PB-228 581

HYPOCHLORINATION OF POLLUTED STORMWATER PUMPAGE AT NEW ORLEANS

Uwe R. Pontius, et al

Pavia-Byrne Engineering Corporation

Prepared for:

Environmental Protection Agency

September 1973

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Monitoring, Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

SELECTED WATER RESOURCES ABSTRACTS

INPUT TRANSACTION FORM

1. Report No. 2.

PB 228 581

W 74-04676

HYPOCHLORINATION OF POLLUTED STORM WATER PUMPAGE AT NEW ORLEANS,

5. Report Date

8. Performing Organization Report No.

Pontius, U.R., Pavia, E.H., and Crowder, D.G.

EPA Project 11023 FAS

Pavia-Byrne Engineering Corporation,
~~431 Gravier St.~~
New Orleans, La. ~~70130~~

1. Type of Report and Period Covered

12. Sponsoring Organization

Environmental Protection Agency, Technology Series report ~~number~~,
EPA-670/2-73-067, September 1973. 188p, 53 fig, 23 tab, 33 ref.

Storm water from the streets of New Orleans flows to large drainage pumping stations where it is discharged into Lake Pontchartrain by means of long outfall canals. To reduce the coliform density, storm water was disinfected with sodium hypochlorite (NaOCl). Project facilities included manufacture, transportation, storage and feeding of 100 gram/l NaOCl. Residual chlorine analyzers were used to monitor NaOCl dosage levels. Sixteen high volume storms totaling 10 to the 9th power gal. of storm water were treated with more than 35,000 gal. of NaOCl. Total and fecal coliform in untreated storm water exceeded 1000 org/100 ml, 99% of the time. Coliform densities in treated water were significantly reduced, with chlorine residuals (total available) of greater than 0.5 mg/l resulting in 99.99% or greater removal. However, rapid recovery of coliform levels occurred within 24 hours. Total coliform recovered to pre-disinfection levels, but fecals did not. The recovery did not appear to be the result of tidal influences. Long term fecal coliform levels were reduced by one order of magnitude in each outfall canal. The amortized cost of NaOCl manufacturing, transporting, feeding and control facilities was $53,600/yr. NaOCl costs for treating 5 times 10 to the 10th power gal. of storm water yearly were $200,300. This resulted in a treatment cost of $.000051/gal. (EPA)

17a. Descriptors *Disinfection, *Chlorination, *Water Pollution Treatment, *Treatment Facilities, *Storm Runoff, Coliforms, Operation and Maintenance, Plastic Pipes, Oxidation-Reduction Potentials, Centrifugal Pumps, Concrete Lined Canals, Protective Coatings, Sodium Compounds, Storage Tanks, *Louisiana, *Waste water treatment

17b. Identifiers
*Hypochlorination, *Sodium Hypochlorite Manufacturing Facilities, *Lined Steel Storage Tanks, *New Orleans, Hypochlorite Feeding Facilities, Residual Chlorine Analyzers

Copy Available from GPO Sup Doc as EP1.23:670/2-73-067, $1.95; microfiche from NTIS as PB PB 228 851 $1.45

05D, 05F

19. Security Class. (Report)

20. Security Class. (Page)

21. No. of Pages 201

22. Price

Send To:

WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U S DEPARTMENT OF THE INTERIOR
WASHINGTON D C 20240

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

EPA-670/2-73-067
September 1973

HYPOCHLORINATION OF POLLUTED STORMWATER PUMPAGE AT NEW ORLEANS

by

Uwe R. Pontius

Edgar H. Pavia, P.E.

Donald G. Crowder

Project #11023 FAS

Project Officer
Robert L. Hiller
Research and Development Representative
Region VI, U.S. Environmental Protection Agency
Dallas, Texas 75201

Prepared for
Office of Research and Development
U.S. ENVIRONMENTAL PROTECTION AGENCY
Washington, D.C. 20460

EPA Review Notice

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

Storm water from the streets of New Orleans flows to large drainage pumping stations where it is discharged into Lake Pontchartrain by means of long outfall canals. To reduce the coliform density, storm water was disinfected with sodium hypochlorite (NaOCl). Project facilities included manufacture, transportation, storage and feeding of 100 gram/l NaOCl. Residual chlorine analyzers were used to monitor NaOCl dosage levels. Sixteen high volume storms totaling 10^9 gal. of storm water were treated with more than 35,000 gal. of NaOCl.

Total and fecal coliform in untreated storm water exceeded 10^3 org/100 ml, 99% of the time. Coliform densities in treated water were significantly reduced, with chlorine residuals (total available) of greater than 0.5 mg/l resulting in 99.99% or greater removal. However, rapid recovery of coliform levels occurred within 24 hours. Total coliform recovered to pre-disinfection levels, but fecals did not. The recovery did not appear to be the result of tidal influences. Long term fecal coliform levels were reduced by one order of magnitude in each outfall canal.

The amortized cost of NaOCl manufacturing, transporting, feeding and control facilities was \$53,600/yr. NaOCl costs for treating ~5×10^{10} gal. of storm water yearly were \$200,300. This resulted in a treatment cost of \$.000051/gal.

This report was submitted in fulfillment of Project # 11023 FAS under the sponsorship of the U.S. Environmental Protection Agency.

CONTENTS

Section No.	Title	Page No.
I	Conclusions	1
II	Recommendations	5
III	Introduction	6
IV	Description, History, and Development of the New Orleans Drainage System	11
V	Design and Construction of Disinfectant Facilities	18
VI	Transportation Equipment	37
VII	Sodium Hypochlorite Storage Facilities	39
VIII	NaOCl Disinfection Facilities	42
IX	Evaluation Program	59
X	Microbiological Aspects of Storm Water and Disinfectants	122
XI	Economics	130
XII	Acknowledgments	135
XIII	References	136
XIV	Project Patents and Publications	139
XV	Glossary and Abbreviations	140
XVI	Appendices	143

FIGURES

Figure No.		Page No.
1	Map of New Orleans and Lake Pontchartrain	7
2	Cross Section of New Orleans	12
3	Map of Present Day Drainage System	15
4	DPS #3 Exterior View of Discharge Side	16
5	DPS #3 Interior View	16
6	Pumping, Rainfall. and Coliform Record - DPS #7 1963	21
7	Averaging Tank and Reactor	23
8	NaOCl Manufacturing Plant	25
9	Flow Sheet - NaOCl Manufacturing Plant	27
10	Control Panel at NaOCl Manufacturing Plant	28
11	NaOCl Reactor	31
12	NaOCl Transport Trucks	37
13	NaOCl Storage and Pumping Facilities DPS #3	44
14	NaOCl Supply Header and Discharge Nozzles	44
15	DPS #3 and #4 - Flow Sheet NaOCl Feeding Facilities	45
16	NaOCl Feedline DPS #4	46
17	DPS #7 Flow Sheet NaOCl Feeding Facilities	48

Figure		Page
18	St. Charles DPS - Flow Sheet NaOCl Feeding Facilities	50
19	Cross Section of St. Charles Reaction Basin	51
20	St. Charles DPS - Reaction Basin	52
21	DPS #7 - Residual Chlorine Analyzer	53
22	St. Charles DPS - NaOCl Control Panel	55
23	Automatic Water Sampler - Interior View	57
24	Exterior View of Metal Building	58
25	DPS #7 Bacterial and Physical Parameters 5 Year Base Period Evaluation	61
26	Schematic Diagram of Drainage System Involved in Project	66
27	Pre-Construction Evaluation Project Sampling Points	69
28	DPS #7 - Pre-Construction Evaluation Program - Bacterial, Rainfall, and Water Pumped Data	70
29	Orleans Ave. Canal (DPS #7) - Pre-Construction Evaluation Program-Total Coliform Histogram	72
30	Orleans Ave. Canal (DPS #7) - Pre-Construction Evaluation Program-Suspended Solids Histogram	73
31	Orleans Ave. Canal (DPS #7) - Pre-Construction Evaluation Program-Dissolved Oxygen Histogram	74

Figure		Page
32	Orleans Ave. Canal (DPS #7) - Pre-Construction Evaluation Program Temperature Histogram	75
33	Pre-Construction Evaluation Program - Total Coliform - Arithmetic Mean vs Time DPS #3, 4, and 7 Discharge	78
34	Pre-Construction Evaluation Program - Suspended Solids - Arithmetic Mean vs Time DPS #3, 4, and 7 Discharge	79
35	Pre-Construction Evaluation Program - Dissolved Oxygen - Arithmetic Mean vs Time DPS #3, 4, and 7 Discharge	80
36	Pre-Construction Evaluation Program - Temperature - DPS #3, 4, and 7 Discharge Arithmetic Mean vs Time	81
37	DPS #7 Pre-Construction Evalution Program - Parameter Levels - % vs Day	82
38	Post-Construction Evaluation Program - Storm Water Sampling Points	91
39	London Ave. Canal (DPS #3 & 4) Total Coliform Levels 5 Year Base Period, Pre-Construction and Post-Construction Evaluation Program	96
40	London Ave. Canal (DPS #3 & 4) Fecal Coliform Levels 5 Year Base Period, Pre-Construction and Post-Construction Evaluation Program	97
41	Orleans Ave. Canal (DPS #7) Total Coliform Levels 5 Year Base Period, Pre-Construction and Post-Construction Evaluation Program	98

Figure		Page
42	Orleans Ave. Canal (DPS #7) Fecal Coliform Levels 5 Year Base Period, Pre-Construction and Post-Construction Evaluation Program	99
43	St. Charles Reaction Basin (St. Charles DPS) Total Coliform Levels 5 Year Base Period, Pre-Construction and Post-Construction Evaluation Program	100
44	St. Charles Reaction Basin (St. Charles DPS) Fecal Coliform Levels 5 Year Base Period, Pre-Construction and Post-Construction Evaluation Program	101
45	DPS #3 Storm Aftergrowth Study	106
46	DPS #7 Orleans Ave. Outfall Canal	107
47	DPS #7 Storm Profile Physical Results Nov. 13, 1972	111
48	Storm Profile Chemical Results Nov. 13, 1972	112
49	DPS #7 Storm Profile Bacterial Results Nov. 13, 1972	113
50	DPS #7 Post-Construction Evaluation Program Average Total Suspended Matter Initial and Final Samples	116
51	Point A - Sampler Inlet at DPS #7	118
52	DPS #7 - Post-Construction Evaluation Program Storm Profile Aftergrowth Study	120
53	Bacterial Growth Curve	123

TABLES

Table No.		Page No.
1	Average Rainfall: 1967-Aug. 1972	13
2	Capacities of Drainage Pumping Stations	17
3	NaOCl Plant Equipment and Material List	33
4	Aging Characteristics of Stored NaOCl	35
5	Bacterial Percentile Levels: 5 Year Base Period	63
6	Rainfall and Water Pumped Frequencies	65
7	Bacterial Percentage Levels: 5 Year Base Period vs Pre-Construction Evaluation	77
8	Means and Standard Deviations Pre-Construction Data 22 Month Analysis	85
9	Coliform Correlation Coefficients	87
10	Post Construction Storm Water Treatment Episodes	93
11	DPS #7 - Pre and Post-Construction Evaluation Program: Means and Standard Deviations of Chemical and Physical Parameters	95
12	DPS #3 - Pre and Post-Construction Evaluation Program: Means and Standard Deviations of Chemical and Physical Parameters	102
13	DPS #4 - Pre and Post-Construction Evaluation Program: Means and Standard Deviations of Chemical and Physical Parameters	103

Table No.		Page No.
14	St. Charles - Pre and Post-Construction Evaluation Program Means and Standard Deviations of Chemical and Physical Parameters	104
15	DPS #3 Storm Sampling, Bacterial, Chemical, and Physical Results	105
16	DPS #7 - Storm Sampling, Bacterial, Chemical, and Physical Results	108
17	DPS #7: Volumetric Time Delays	110
18	DPS #7 - Maximum Coliform Reduction for Sixteen Storm Profiles	117
19	Fixed Costs: NaOCl Manufacturing Plant	131
20	Average Cost of Manufacturing NaOCl	132
21	Fixed Costs: NaOCl Feeding Facilities	132
22	Fixed Costs: Chemical Feed Systems	133
23	Total Fixed Costs	133

SECTION I

CONCLUSIONS

1. Demonstration of the feasibility of reducing total coliform and fecal coliform levels in large volumes of storm water by chemical disinfection and of the effectiveness of utilizing open channels in populated areas as treatment facilities met with unqualified success. It was also possible to reduce the coliform levels of storm water discharged into the outfall canals. However, recovery of coliform levels after 24 hrs obscured the goal of coliform reduction in water ultimately discharged to the lake since treated water could remain in the outfall canal for days or weeks after treatment.

2. NaOCl was added to storm water during 16 high volume storm and more than 20 low volume storms. During the 16 high volume storms, 1.04×10^9 gals. of storm water were treated with more than 3.5×10^4 gals. of NaOCl. The largest single treatment episode was 6.8×10^7 gals. of storm water with 8.1×10^3 gals. of NaOCl. Sampling programs both before and during hypochlorination were extensive with more than 2600 water samples taken for analysis. The resulting data set exceeded 26,000 items.

3. Pre-Construction Sampling Programs indicated that 99% of the total coliform densities in the storm water reaching the pumping stations were greater than the 1,000 org/100 ml recommended for body contact recreation areas by the Louisiana State Board of Health. Fecal coliform densities were also high with 99% greater than 100 org/100 ml.

4. From a consideration of the 16 high volume storms, chlorine residuals greater than 0.5 mg/l resulted in 99.99% or greater reduction of bacterial densities. For several storms minimum bacterial densities after disinfection were 100 org/100 ml for total coliform, and <10 org/100 ml for fecal coliform.

5. Upon cessation of disinfection, coliform bacterial levels in the outfall canals recovered within 24 to 30 hours. Total coliform recovery levels of 10^6 org/100 ml were comparable to those normally found in the outfall canals. Fecal coliform recovery levels of 10^3 org/100 ml were approximately two orders of magnitude less than normal endogenous levels. Tidal influences did not appear to be a factor.

6. The coliform bacteria surviving disinfection are on the logarithmic growth phase and the declining growth phase for the first 24 to 30 hours. This can result in rapid recovery

of the bacterial population to that level normally found in the outfall canal. This rapid recovery changes significance of the coliform levels. Their use as indicators of possible pathogenicity of the storm water is obscured once disinfection has occurred.

7. Since there are over 10×10^6 cu ft of water and associated benthos in most of the outfall canals, it is not economically possible or ecologically desirable to keep a chlorine residual in the outfall canal at all times to prevent coliform level recovery. Also, pathogens are not likely to reproduce in the harsh environment encountered in the outfall canals.

8. With recovery of indicator bacteria after disinfection, the environmental conditions in the outfall canals dictate the levels and viability of pathogens in the disinfected storm water. The important environmental considerations are: (1) temperature, (2) interference of growth due to competing microorganisms, (3) time since introduction of microorganisms, (4) the initial and subsequent effects of substances such as NaOCl or other inhabiting chemicals either from natural or manmade sources, and (5) the presence of solid materials in the water which can shelter the microorganisms from attack.

9. BOD, COD and suspended solids levels in the outfall canals indicated that 99.5% of the BOD values <50 mg/l, 97.7% of the COD values <175 mg/l, and 95.1% of the suspended solids levels <100 mg/l. The majority of values which exceeded these levels occurred just after initiation of pumping.

10. Long term levels of fecal coliform in the outfall canals were reduced by one or more orders of magnitude at each pumping station where NaOCl was added. Long term total coliform levels were approximately the same as pre-disinfection values, except for a one order of magnitude reduction at one pumping station where all storm water was disinfected.

11. The automatic, continuous, sodium hypochlorite (NaOCl) manufacturing plant, utilizing a patented process, is capable of producing 1,000 gal./hr of 120 gram/liter NaOCl under atmospheric conditions. This method of manufacture proved to be extremely safe and reliable during the project.

12. The two, 3,000 gal., lined steel transport trucks were able to maintain NaOCl stores at the pumping stations with no difficulty. Both trucks were fully operational at the termination of the project and appear suitable for transport of high strength NaOCl.

13. High strength NaOCl was stored in 20,000 gal., cylindrical, lined steel storage tanks. The tanks were lined with white natural rubber, flexible hard rubber, and polyethylene. The storage tanks were in operation for four years under ambient temperature and high NaOCl concentration conditions. During this period no failures of any tanks have occurred. Thus, these linings seem suitable for containment of high strength NaOCl.

14. The field half life of the stored NaOCl, with an initial concentration of greater than 90 grams/liter, exposed to ambient conditions (March through August), averaged 133 days. Thus, the use of 20,000 gals., cylindrical, lined steel tanks appears to be a quite satisfactory storage method for high strength NaOCl.

15. The intermittent pumpage of high strength NaOCl with long term contact between pumpage results in the rapid failure of polypropylene lined NaOCl pump and ORP cell mountings.

16. Chlorine residual (Cl_2R) analyzers used to indicate treatment levels performed adequately after a continuous water supply was installed for operation between storm pumpages. This modification resulted in an inordinate use of buffer chemicals for the operation of the analyzer. At present, there do not exist any residual chlorine analyzers which can be used intermittently on storm water without major modification.

17. The automatic discrete water sampler designed and constructed for the project operated satisfactorily. However, sampling intake heads, located in the storm water streams with high velocities, were ineffective as the sample head would tilt and break prime on the sample pump.

18. The addition of NaOCl at a point prior to the pumping of storm water resulted in excellent mixing of the NaOCl with the storm water. One location where a constriction of flow in the outfall canal was to provide for complete mixing was not effective as channeling of the water took place. This resulted in inadequate mixing of the storm water and disinfectant.

19. The addition of NaOCl to polluted storm water involves eight major cost elements: (1) land, (2) manufacturing facilities, (3) transportation facilities, (4) storage facilities, (5) chemical feed systems, (6) chemicals, (7) operation and maintenance, and (8) amortization cost.

20. The total cost of facilities was \$53,600/yr. The cost of manufacturing $NaOCl$ to treat 5×10^{10} gals. of storm water per year, with a chlorine demand of 3.5 mg/l, at a level of 1.0 mg/l residual, is \$200,300. On this basis, the average treatment cost is \$.000051/gal. of storm water.

SECTION II

RECOMMENDATIONS

1. Disinfection should be continued in order to decrease levels of possible pathogens even if coliform levels recover since the environmental conditions are not favorable for pathogen regrowth.

2. Controlled microbiological studies of the recovery phenomenon, in situ, are indicated. Specific tests for pathogens should be included as well as the standard coliform procedures in order to ascertain the proper use of coliform levels in controlling storm water discharge after disinfection and to study the various parameters affecting pathogen removal in treated storm water.

3. Chlorine residuals of 0.5 mg/l should be maintained since contact time is sufficiently long to decrease the levels of coliform to less than the 1000 org/100 ml suggested for body contact recreation areas by the Louisiana State Board of Health.

4. The point of disinfectant addition should be prior to storm water pumpage whenever possible so that adequate mixing will take place. This is expecially desirable from the standpoint of rupturing large clumps of material and allowing maximum NaOCl contact.

5. Since shut down of residual chlorine analyzers between periods of storm water disinfection resulted in rapid failure of the analyzers, a constant water supply should be provided whenever this equipment is used intermittently. In addition, the excessive cost of buffer chemicals for the machines should be circumvented by mixing the necessary chemicals in bulk on site, rather than using commercially available mixtures.

6. In order to decrease the adverse effects of long term contact with high strength NaOCl, all equipment should be flushed with water between usages, when possible. This would be a much less expensive procedure in the long term when considering the disparity (10:1) in the initial cost of the polyethylene versus all titanium equipment.

7. The possibility of using ORP readings in a feedforward loop to control disinfectant feed should be studied. Residual chlorine feedback signals could be used as an overriding parameter.

SECTION III

INTRODUCTION

The project, "Hypochlorination of Polluted Storm Water Pumpage at New Orleans", consisted of demonstrating the use of sodium hypochlorite (NaOCl) for disinfecting storm water pumped from the east bank of the city of New Orleans into Lake Pontchartrain (Figure 1). Initiated in December, 1966, the project also included the construction of NaOCl manufacturing, delivery, and monitoring systems. Two extensive data acquisition and analysis programs were carried out to evaluate the short and long term effects of disinfection on the quality of the water subsequently discharged to Lake Pontchartrain. The project was completed in September of 1972.

The project had three basic purposes:

1. To demonstrate the feasibility of reducing the total and fecal coliform count in large volumes of storm water by chemical disinfection.
2. To demonstrate the effectiveness of utilizing open channels in populated areas as treatment facilities.
3. To reduce the coliform bacteria levels of storm water discharged into Lake Pontchartrain, a recreational body of water.

The feasibility of reducing the total and fecal coliform counts in large volumes of storm water by chemical disinfection and the demonstration of the effectiveness of utilizing open channels in populated areas as treatment facilities met with unqualified success. Coliform levels were reduced in the outfall canals after treatment with no apparent deleterious effects on surrounding residential areas from hypochlorination. However, the determination of bacterial levels in the surrounding waters of Lake Pontchartrain with respect to the treated water was not possible since several days to several weeks could pass before treated water would leave the 10,000 ft long outfall canals. Since coliform levels recovered during this time, the concept of coliform control became obscured. In addition, the number of samples taken in the lake were insufficient to determine the causative source of either increase or decrease of coliform levels. This is due to the large size of the lake, and numerous points of discharge other than the treated water from the outfall canals. However, levels of coliform at points of immediate discharge into the lake were lowered. (32)

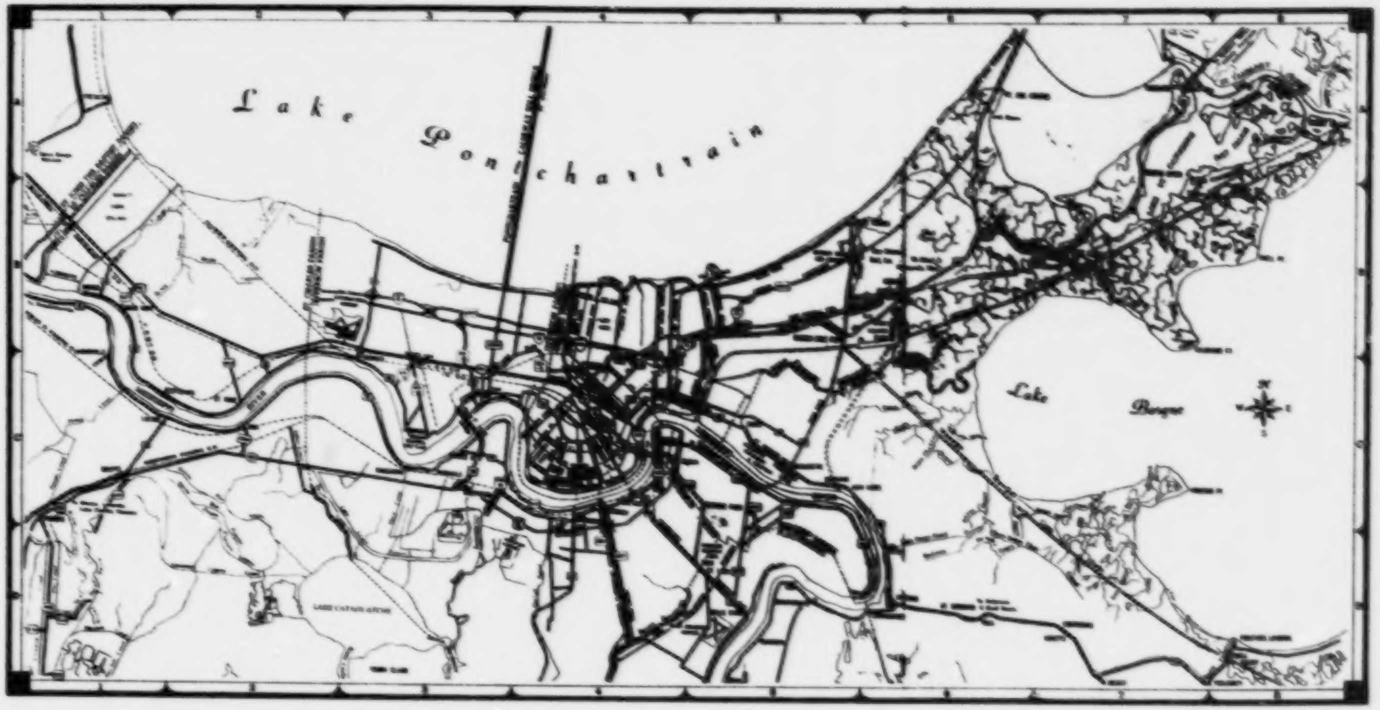

Lake Pontchartrain
Lake Borgne

FIGURE 1 MAP OF NEW ORLEANS & LAKE PONTCHARTRAIN

FACILITIES

The project was initiated after data taken between 1961 and 1966 (Five Year Base Period) indicated that storm drainage water being pumped from the east bank of New Orleans into Lake Pontchartrain was grossly polluted with indicator bacteria. Since an elevated level of indicator bacteria was the only form of gross pollution demonstrated by the base period data, it was felt that disinfection on a large scale would be adequate to restore the quality of the water to an acceptable level. To accomplish this, it was decided to add disinfectant to the storm water pumped by four drainage pumping stations (DPS), DPS #3, DPS #4, DPS #7, and St. Charles, which are located on three outfall canals on the east bank of New Orleans. The four DPS have a combined pumping capacity of 11,050 cfs and each normally pumps in excess of 20,000,000 cfd of storm water on rainy days.

Due to the large amount of polluted water being pumped and the concomitant requirement for large quantities of disinfectant, the project included the design and construction of a NaOCl manufacturing plant to prepare the disinfectant used during the demonstration phase. Disinfectant prepared at the NaOCl manufacturing plant was stored at feeding facilities located adjacent to each pumping station in the project. In order to evaluate the effects of feeding NaOCl to the polluted storm water, sampling facilities were installed at each pumping station. Analytic equipment at the sampling facilities consisted of water samplers, amperometric residual chlorine analyzers, temperature probes, and dissolved oxygen (DO) meters.

EVALUATION PROGRAM

The first data acquisition program consisted of a 22 month Pre-Construction Evaluation Program whose purpose was to provide base line bacterial, chemical, and physical levels for each canal, from which changes produced by the addition of NaOCl could be determined. The 22 month Pre-Construction Evaluation Program consisted of obtaining grab samples of water in the suction bays and outfall canals at regular intervals and analyzing these samples for applicable sanitary parameters, i.e., total coliform, fecal coliform, chemical oxygen demand (COD), biochemical oxygen demand (BOD), chlorine demand (ClD), and solids. The data acquired from these grab samples as well as that from the Five Year Base Period was then used to generate statistics which characterized the quality of the drainage water normally found in the system.

Upon completion of construction, a Post-Construction Evaluation

Program continued the routine sampling of the open outfall canals between periods of disinfectant feeding so that the long term effects of disinfection could be determined. Additionally, low volume storm and high volume storm profile samples were taken. Storm sampling provided composite samples of untreated storm water in the suction bays of the pumping station and chlorinated samples from the discharge side after disinfection during low volume pumping episodes. The composite samples were evaluated immediately. When possible, portions were then stored and sampled again at 24 hour intervals for three days in a bacterial aftergrowth study. A storm profile consisted of numerous samples taken prior to and after the addition of the disinfectant during periods of high rates of storm water pumpage. One storm profile aftergrowth study was performed by operating a sampler at the outfall canal for 30 hours, at two hour intervals following disinfection. Additionally, samples were taken in Lake Pontchartrain weekly during the Pre-Construction Evaluation Program and after storms during the Post-Construction Evaluation Program.

RESULTS

Weekly sampling during the post-construction period indicated that few changes had taken place in the outfall canals and suction bays of the various pumping stations in the project since the Pre-Construction Evaluation Program. There were minor changes of the chemical and physical parameter levels, but these were within the range of the pre-construction base lines. Total coliform levels at DPS #3, #4, and St. Charles remained high and other parameters were of comparable values. However, fecal coliform values in the outfall canals at all stations between episodes of NaOCl addition showed significant decreases from those of the Pre-Construction Evaluation Program. Additionally, the long term total coliform level at DPS #7 has been lowered. This trend was obvious even though rapid recovery of indicator coliform levels in the outfall canals occurs after residual chlorine levels disappear. However, fecal coliform levels do not recover to pre-treatment levels. Thus, as discussed later, the indicator significance of the coliform group is obscured once NaOCl has been added to the water. Pathogens are not likely to reproduce in the outfall canals, but regrowth of non-pathogenic bacteria is a natural and expected phenomenon. During storm profiles, bacterial densities were greatly reduced in the storm water which had NaOCl added to it. Removals of greater than 10^4 org/100 ml (99.99%) were demonstrated with residual chlorine levels >0.5 mg/l. No substantial results could be gleaned from the lake samples since an insufficient number were taken to account for the many factors which influence the coliform levels in the lake.

SECTION IV

DESCRIPTION, HISTORY AND DEVELOPMENT OF THE NEW ORLEANS DRAINAGE SYSTEM

BACKGROUND

New Orleans was founded in 1718 on the banks of the Mississippi River 100 miles from its mouth. Originally the land area was an impenetrable swamp bounded by streams and lakes. The city lay between the Mississippi River and Lake Pontchartrain, both of which were subject to flooding during certain periods of the year. In fact, the river overflowed its banks and flooded the small community consisting of 66 square blocks within the first year.

TOPOGRAPHY

The topography of New Orleans is shown in a typical cross section through the city (Fig. 2). It can be seen that the elevation of the city ranges from +12 ft to -8 ft msl, with the vast majority of the land area being below +2 ft msl. For this reason, it has been necessary to construct levees along both the Mississippi River and Lake Pontchartrain to protect the city from floods. The levees along the Mississippi River have a crown elevation of +25 ft msl. The levees along Lake Pontchartrain are being raised to a level of +13 ft msl to protect the city from hurricane tides of +11 ft msl.

RAINFALL

The erratic nature and quantity of rainfall is an additional complication in providing adequate drainage for New Orleans. Since 1893 when rainfall records were initiated, the average annual rainfall for the city has been 57.54 in./yr. The mean annual rainfall average has varied from 33.5 in. in 1917 to 79.21 in. in 1929. The average monthly rainfall varies from 3.21 in. to 6.60 in. although monthly rainfalls of .06 in. in April, 1915 and 24.62 in. in October, 1937 have been recorded. The months of July and August are usually the wettest months of the year, and October and November the dryest. During the period of this program, New Orleans has experienced a relatively dry period. It can be seen in Table 1 that the rainfall of 60.94 in. during 1967 and 58.34 in. in 1970 were the only annual rainfalls which

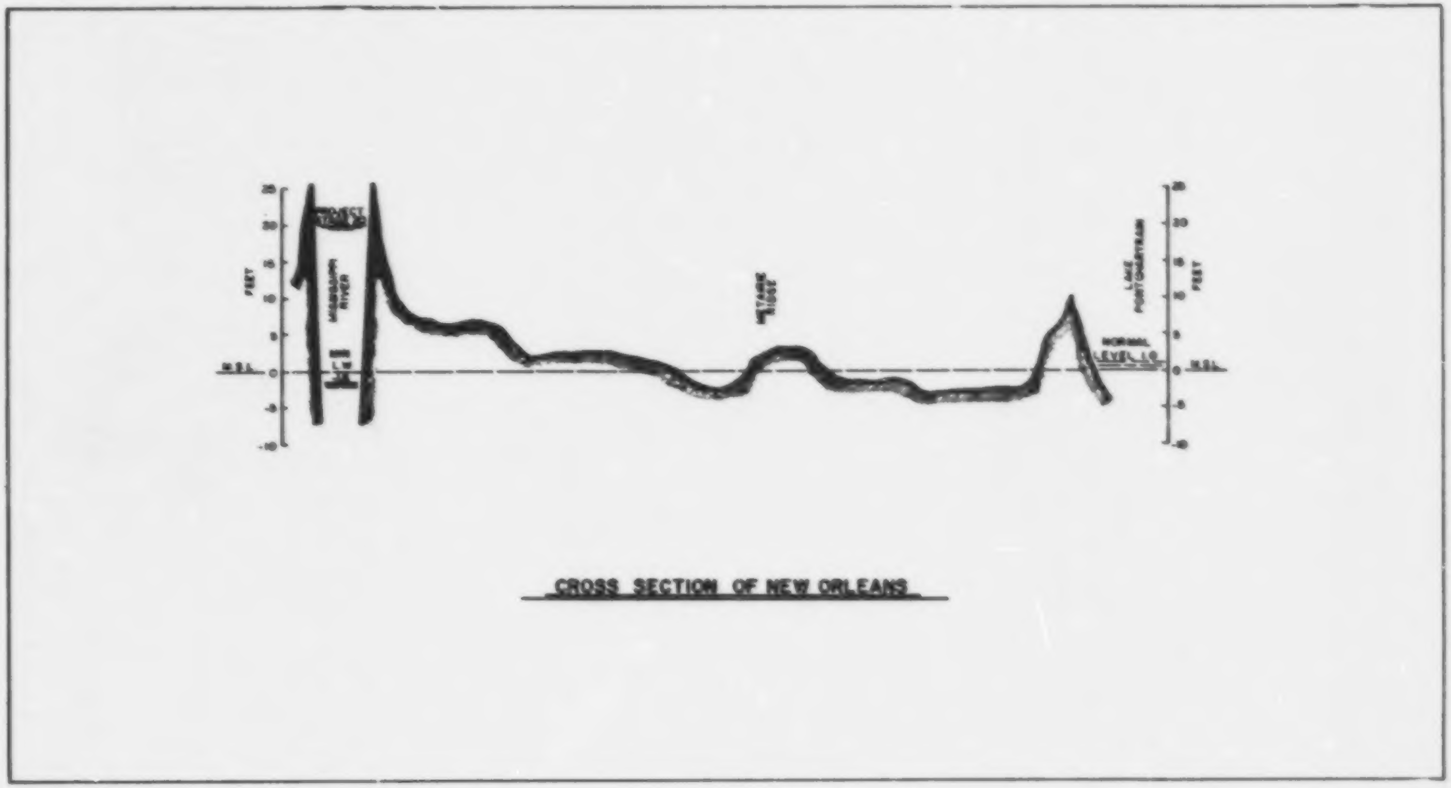


FIGURE 2. CROSS SECTION OF NEW ORLEANS

exceeded the 78 year average during the last five years.

TABLE 1

AVERAGE RAINFALL: 1967 - AUGUST, 1972

78 YEAR AVERAGE = 57.54 in./yr

YEAR	RAINFALL (in.)	% EXCESS OF 78 YEAR AVERAGE
1967	60.94	+ 5.71
1968	50.70	-13.33
1969	52.11	-10.26
1970	58.34	+ 1.50
1971	55.57	- 3.23
1972	37.12 (R_{78}=40.73)	- 8.89

For the eight month period, January through August 1972, the average rainfall was 8.9% below normal.

EARLY DRAINAGE SYSTEM

The development of the present drainage system began in 1893 when a group known as the Engineering Committee was organized to develop a general plan for storm drainage of the city. The original master drainage plan included construction of tributary canals, pumping stations, and outfall canals to the lakes. The main outfall canal was located at the lowest depression between the river and the ridges, and ran across the city from west to east before discharging into Bayou Bienvenue and thereby to Lake Borgne. This outfall canal was designed to carry dry weather flow and light rain drainage water directly to Lake Borgne. It would also be used as a header for three relief outfall canals capable of discharging water from the main canal directly to Lake Pontchartrain. Four pumping stations were located along the main canal: DPS #1, #2, #3, and #5. DPS #6, and #7 were constructed along two of the outfall canals and discharged water directly into Lake Pontchartrain. DPS #3 has the capability to discharge water either into the main canal (Lake Borgne) or into the London Avenue Canal (Lake Pontchartrain). The route of drainage water is dependent on the available capacity of the main canal. Priority was given to the main canal for drainage as originally this canal required less lift. Storm water not handled by the main canal was routed to the outfall canals. The main canal remains in use today as the Broad

Street - Florida Avenue system. DPS #3, #6, and #7 remain in operation as three of the largest pumping stations in the system with capacities of 4,100 cfs, 6,000 cfs, and 3,150 cfs respectively. With this plan prepared, the Louisiana legislature created a Drainage Commission in New Orleans in 1896 to finance and construct the permanent drainage system.

MODERN DRAINAGE SYSTEM

Drainage Criteria

The present storm drainage system provides for removal of rainfall at the rate of two inches for the first hour, plus 0.5 in./hr thereafter. A storm of this intensity is normally experienced only once each year. The present drainage system is designed to remove this rainfall with a runoff coefficient of 85%.

Present Drainage System

The present drainage system for the East Bank of New Orleans, a map of which is shown in Figure 3, is essentially a modernized version of the drainage system originally conceived in 1896. The drainage system includes over 1,400 miles of subsurface drainage, 225 miles of canals, and 16 pumping stations which have a combined capacity in excess of 30,000 cfs (13,465,000 gpm). The 213 miles of canals vary in cross section with the largest being 28 ft wide by 14 ft deep. The majority of uncovered canals are outfall canals carrying water from the pumping stations to Lake Pontchartrain. These outfall canals are up to 250 ft wide and 10 ft deep. Of the 16 pumping stations, 13 are located on the East Bank of the city. These 13 pumping stations have the capacity to pump in excess of 18,000 cfs into five outfall canals draining into Lake Pontchartrain. Three of these outfall canals, the Metairie Relief Canal, the Orleans Avenue Canal, and the London Avenue Canal lie west of the Industrial Canal. Each individual pumping station has its own set of pumps having different capacities. The capacities of the individual pumps range up to 1,100 cfs and several stations have total capacities of 6,000 cfs. The tabulation of the pumps and pumping capacity at the pumping stations in the project is shown in Table 2.

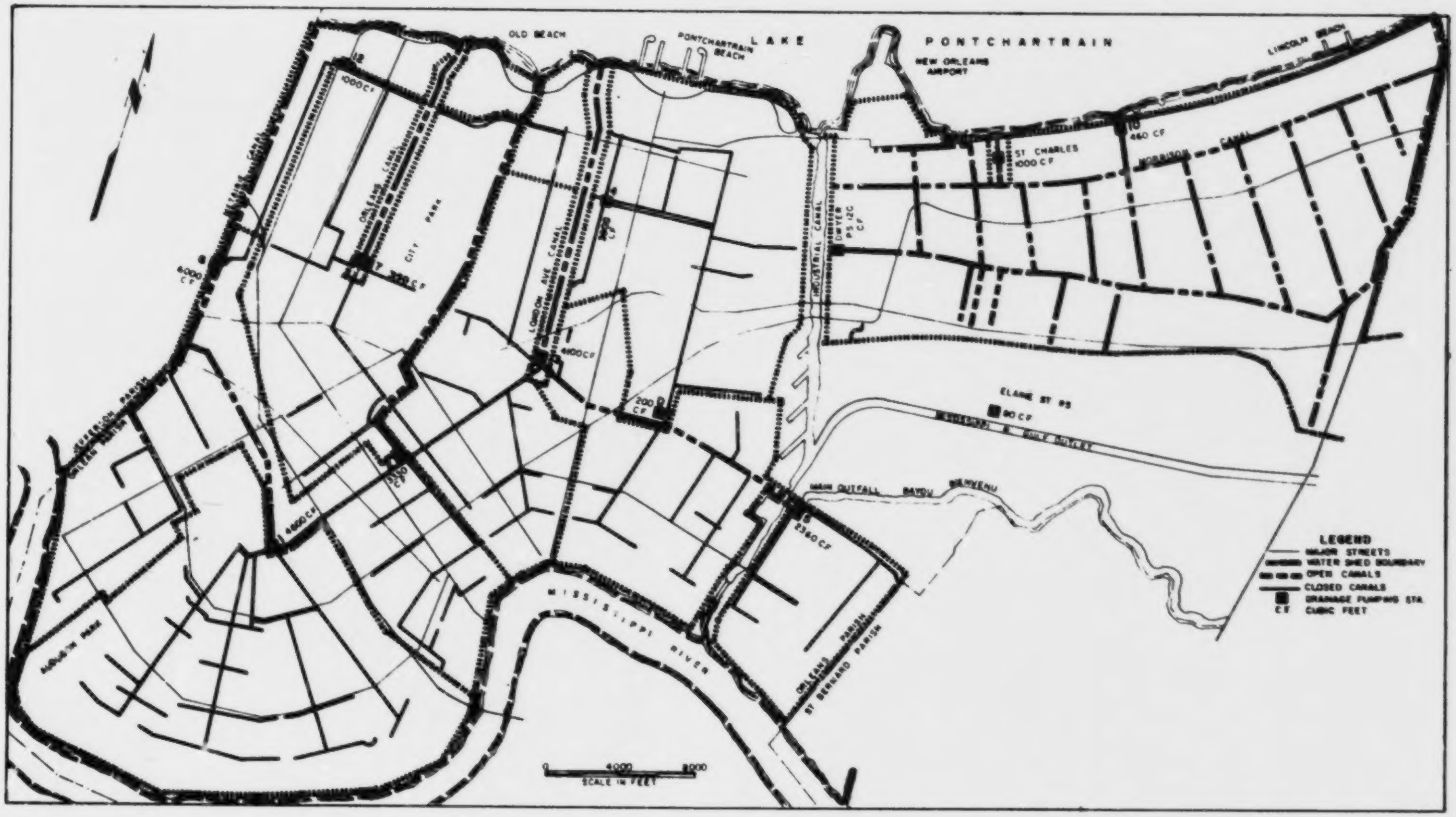

OLD BEACH
PONTCHARTRAIN BEACH
LAKE PONTCHARTRAIN
NEW ORLEANS AIRPORT
LINCOLN BEACH
ST CHARLES 1000 CF
10 460 CF
MORRISON CANAL
INDUSTRIAL CANAL
DWYER PS 12C CF
ELAINE ST PS
80 CF
MAIN OUTFALL BAYOU BIENVENU
2360 CF
ORLEANS PARISH
ST BERNARD PARISH
MISSISSIPPI RIVER
12
1000 CF
ORLEANS CANAL
CITY PARK
7 320 CF
6000 CF
LONDON AVE CANAL
4100 CF
200 CF
4600 CF
JEFFERSON PARISH
ORLEANS PARISH
AUDUBON PARK
0 4000 8000
SCALE IN FEET
LEGEND
MAJOR STREETS
WATER SHED BOUNDARY
OPEN CANALS
CLOSED CANALS
DRAINAGE PUMPING STA
C F CUBIC FEET

FIGURE 3. MAP OF PRESENT DAY DRAINAGE SYSTEM

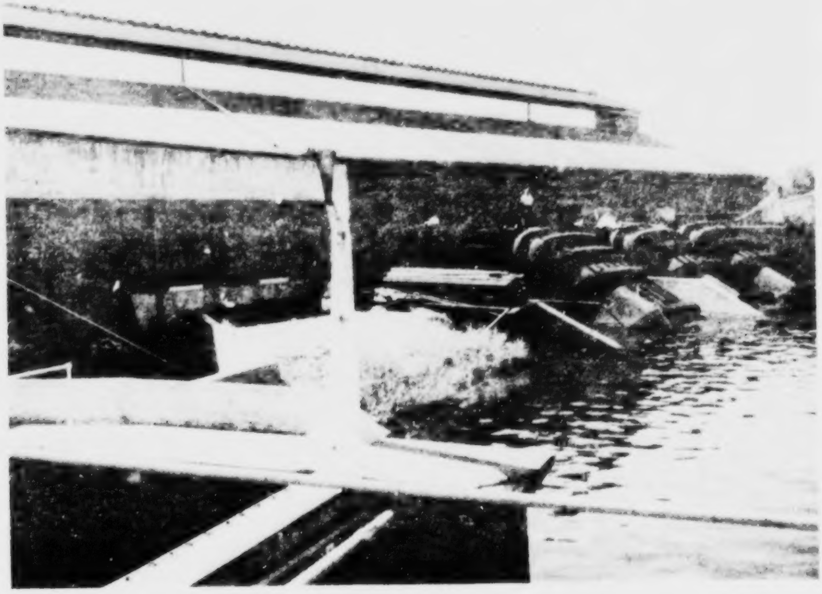


FIGURE 4. DPS #3 - EXTERIOR VIEW OF DISCHARGE SIDE.

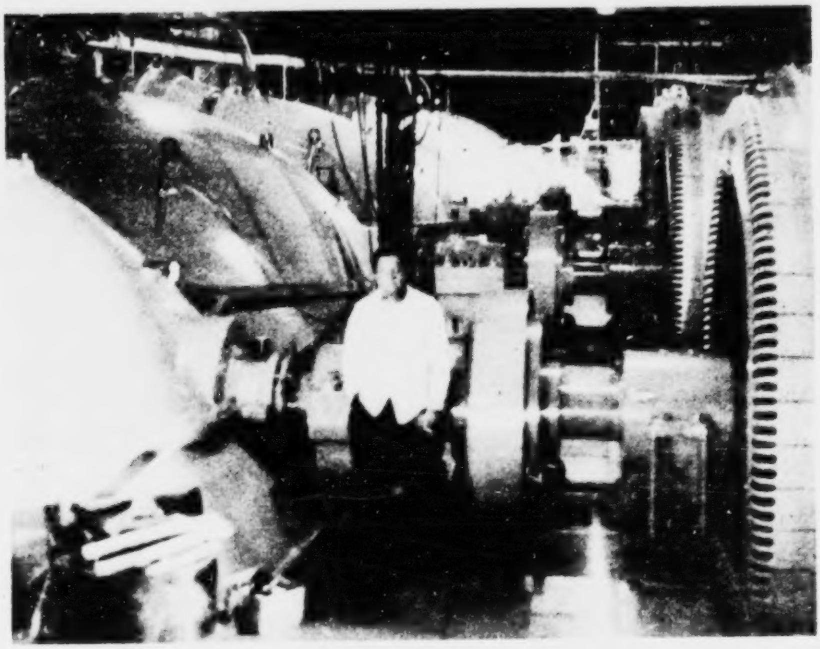


FIGURE 5. DPS #3 - INTERIOR VIEW

TABLE 2

CAPACITIES OF DRAINAGE PUMPING STATIONS

STATION	NO. PUMPS	TOTAL CAPACITY (cfs)
#3	5	4,100
#4	5	3,900
#7	6	3,150
St. Charles	4	1,000

The pumps at the pumping stations can move the rated flow against a pool to pool head of 14 ft. This head represents the difference in water level between the suction bay at the pumping station and the tidal elevation in the outfall canal. The pumping stations of the original drainage plan are still in use. They have been updated and modernized but amazingly still utilize some of the original pumps. An exterior and interior view of DPS #3, located on the London Avenue Canal, is shown in Figures 4 and 5. This station was originally constructed in 1899 by the New Orleans Drainage Commission and was subsequently remanded to the Sewerage and Water Board in 1903. Today, it serves as one of the major stations in the New Orleans drainage system. The Sewerage and Water Board has recently placed in operation its first fully automatic major pumping station, the St. Charles station. This pumping station is located in the eastern part of the city. Pumping stations crucial to the drainage system are continuously manned. Other pumping stations are manned only when rain is forecast or falling.

SECTION V

DESIGN AND CONSTRUCTION OF DISINFECTANT FACILITIES

GENERAL

The design and construction of the facilities for this project required much work not anticipated in the original planning stages. Additionally, most of the equipment had to be designed specifically for the application, e.g., the automatic samplers located at the feeding facilities. Also, the use of high strength NaOCl required an in depth investigation of the performance of materials under the stringent conditions of long periods of NaOCl contact. The construction phase consisted of six separate programs:

1. Sodium hypochlorite manufacturing plant.
2. Chemical storage facilities at the manufacturing plant.
3. Sodium hypochlorite transportation equipment.
4. Sodium hypochlorite storage and feeding facilities at the points of application.
5. Automatic samplers to provide refrigerated, discrete water samples for analytical work.
6. Data acquisition and residual chlorine analyzer installations which monitor and control disinfectant feed.

The NaOCl manufacturing plant designed and constructed for this project is of a novel design which has been patented (1). The design has resulted in a process to continuously manufacture high strength sodium hypochlorite under atmospheric conditions. This method of manufacture is much safer than those methods that have been available heretofore. The patents on this process have been licensed to the United States government and Sewerage and Water Board of New Orleans for use in all pollution control work.

Each of the facilities will be discussed separately. Where trade names of commercial products are used, their use does not imply endorsement either by the engineer, the Sewerage and Water Board of New Orleans or the Environmental Protection Agency.

SODIUM HYPOCHLORITE PLANT

General

The decision to use high strength NaOCl as a disinfectant for bacterially polluted storm drainage water had been made prior to applying for federal participation. The Sewerage and Water Board of New Orleans had by its own volition decided to feed disinfectant to storm water being pumped by the new St. Charles Station for the purpose of determining its effectiveness in reducing total and fecal coliform levels. Under the provisions of the Federal Water Pollution Control Act of 1965, as amended, the original plan of the Sewerage and Water Board was extended to include DPS #3, #4, and #7 which lie on the London Avenue and Orleans Avenue Canals.

Quantity and Strength of NaOCl

With the decision to utilize NaOCl as a chemical disinfectant, investigations were started to determine the required quantity and strength of this material in treating the storm water pumped to the outfall canals. Provisions were made for feeding up to 10 mg/l of available chlorine to the storm water based on a possible requirement for superchlorination dosages. It was decided that water pumped during tropical storms and hurricanes would not be treated. With this exception, however, the capability to treat 99% of normal pumping periods was required since swimming beaches at the lake are used year round. Evaluation of the available space and operating characteristics of each pumping station involved in the demonstration program resulted in a decision to use NaOCl in a concentration of approximately 96 gpl. Consumption was determined by analyzing quantities of water pumped during a five year base period, July 1, 1961 to June 30, 1966. Pumping, rainfall, and coliform records for DPS #7 on the Orleans Avenue Canal for 1963 are shown in Figure 6. Based on the Five Year Base Period data, a maximum of 20,000 gallons per pumping day of 96 gpl NaOCl would have been used at each of the pumping stations in the program. An analysis of the wettest five day period indicated that each of the three pumping stations originally slated to use NaOCl would have required a total of 40,000 gallons of NaOCl. Due to the relatively short life of commercially available NaOCl, the disinfectant would have to be available on a very rapid replacement basis or disinfectant of a higher strength would be required. An evaluation of the NaOCl deterioration curve indicated that if the disinfectant were supplied at a concentration of 120 gpl, it would normally be used before it had deteriorated below 96 gpl. The regular suppliers of NaOCl in the New Orleans area were contacted and their interest in furnishing disinfectant for the project was determined. None were interested in a short term contract for the quantities and concentration required and the construction of an NaOCl manufacturing plant was required.

Design of NaOCl Manufacturing Plant

The NaOCl manufacturing plant was located at the water purification plant of the Sewerage and Water Board of New Orleans due to the availability of personnel experienced in handling large quantities of chlorine. Since the water purification plant is located in a residential and semi-commercial area, the utmost degree of safety had to be designed into the NaOCl manufacturing plant. The final design was for a continuous, automatically controlled manufacturing plant with a capacity to manufacture 1,000 gal./hr of 120 gpl NaOCl with a storage of 40,000 gal. of finished NaOCl at the manufacturing plant. The design criteria met the maximum demand for NaOCl and the plant was operated as required during the periods of lower demand to keep the feeding facilities at the pumping stations supplied with suitable strength NaOCl.

Process Design

NaOCl is commonly manufactured by reacting sodium hydroxide, chlorine, and water. The reaction is exothermic and is very sensitive to the temperature of reaction. If the temperature of reaction exceeds a value of 86°F to 90°F, sodium chlorate, an inert material, which is of no value for disinfection, is formed. For this reason, high strength NaOCl is commonly manufactured in a batch type operation with manual control of the addition of chlorine. The reaction takes place either in concrete or rubber lined vats with cakes of ice or refrigerant coils being used to absorb the heat of reaction. When ice is used, it provides part of the water required for the manufacture of the finished product. The batch operation is wholly dependent on the operator for the control of chlorine addition and for the quality of the finished product. Due to the intermittent high level demand for the disinfectant, the process was designed to provide for the manufacture of NaOCl on an automatic, continuous basis.

Investigations of the commonly available reactors for continuously manufacturing high strength NaOCl revealed that

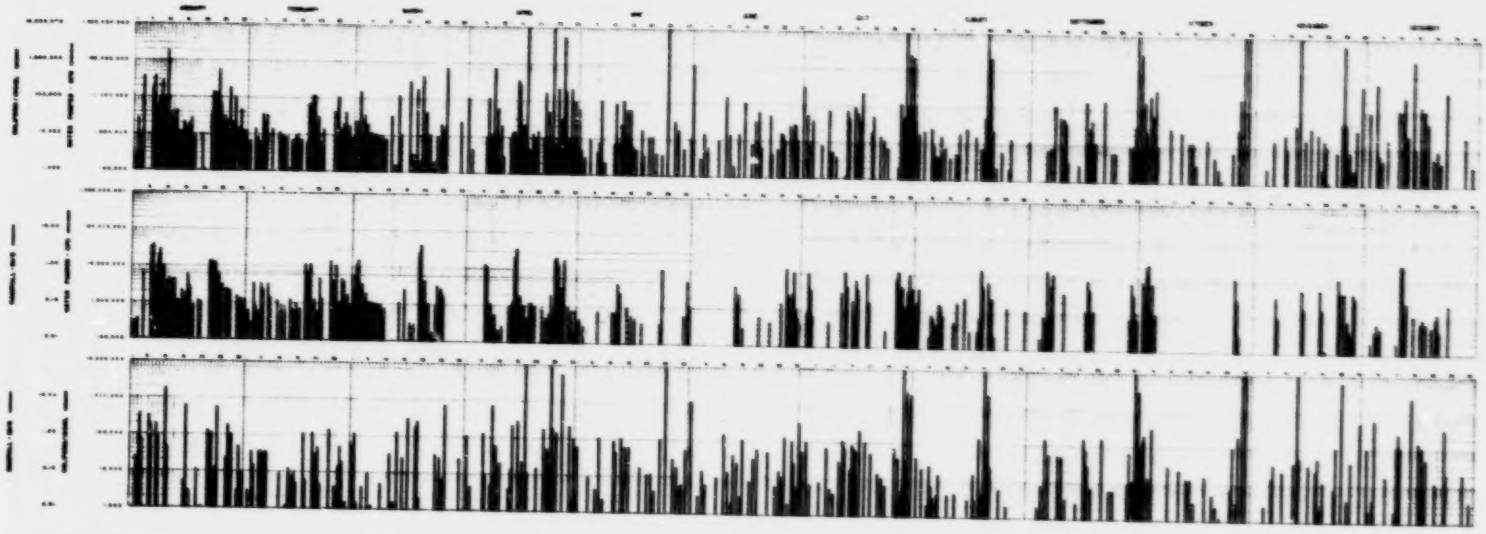


FIGURE 6. PUMPING, RAINFALL, & COLIFORM RECORD - DPS #7 1963

these reactors generally operated under pressure. Due to the location of the plant, it was felt that this would be an undesirable feature from the standpoint of safety and should be avoided if possible. Thus, it was felt that the process design should have the following features:

1. It would operate at atmospheric pressure.
2. It would control the temperature of the reaction so that it would never exceed 86°F.
3. It would be constructed of materials resistant to water, sodium hydroxide, liquid and gaseous chlorine, and sodium hypochlorite.

The requirement that the reactor operate at atmospheric pressure implies that the chlorine must react completely prior to reaching a free surface. In batch type operations, chlorine is usually introduced into the reaction tank approximately 8 feet below the surface. Pilot studies were carried out and indicated that a horizontal reactor providing an equivalent retention time would suffice. However, an averaging tank was placed at the end of the reactor to provide additional mixing time. (Fig. 7)

Liquid chlorine is used directly from tank cars, without vaporization to gaseous chlorine, and blended with a previously diluted 14% NaOH solution. This procedure results in a reduction of the heat of reaction of approximately 16%. The heat generated by chlorine when combined with NaOH is 526 BTU per pound of liquid chlorine. Production of 120 gpl NaOCl, at a rate of 1,000 gal./hr results in the generation of 527,052 BTU which is equivalent to 44 tons of refrigeration. Since the reaction to form 120 gpl NaOCl requires chlorine to be added to a 14% solution of NaOH, the possibility of using precooled 14% NaOH as the heat sink was considered. It was calculated that 14% NaOH would have to be cooled to 14°F to provide a sufficient heat sink to absorb the heat of reaction. However, 14% NaOH has a crystallization temperature of 11°F, and it was deemed that the three degree difference between the two temperatures did not provide an adequate safety margin. Thus, another heat sink had to be found. It had been previously determined that the finished NaOCl would be cooled to 60°F in order to improve its life span. Thus, adding a sufficient amount of manufactured and cooled NaOCl to the reacting mixture served as the second heat sink. Using a recirculation of 2.23 volumes of finished NaOCl at 60°F, it was found that the 14% NaOH solution would only have to be cooled to 60°F for the combination to provide a sufficient heat sink. This design

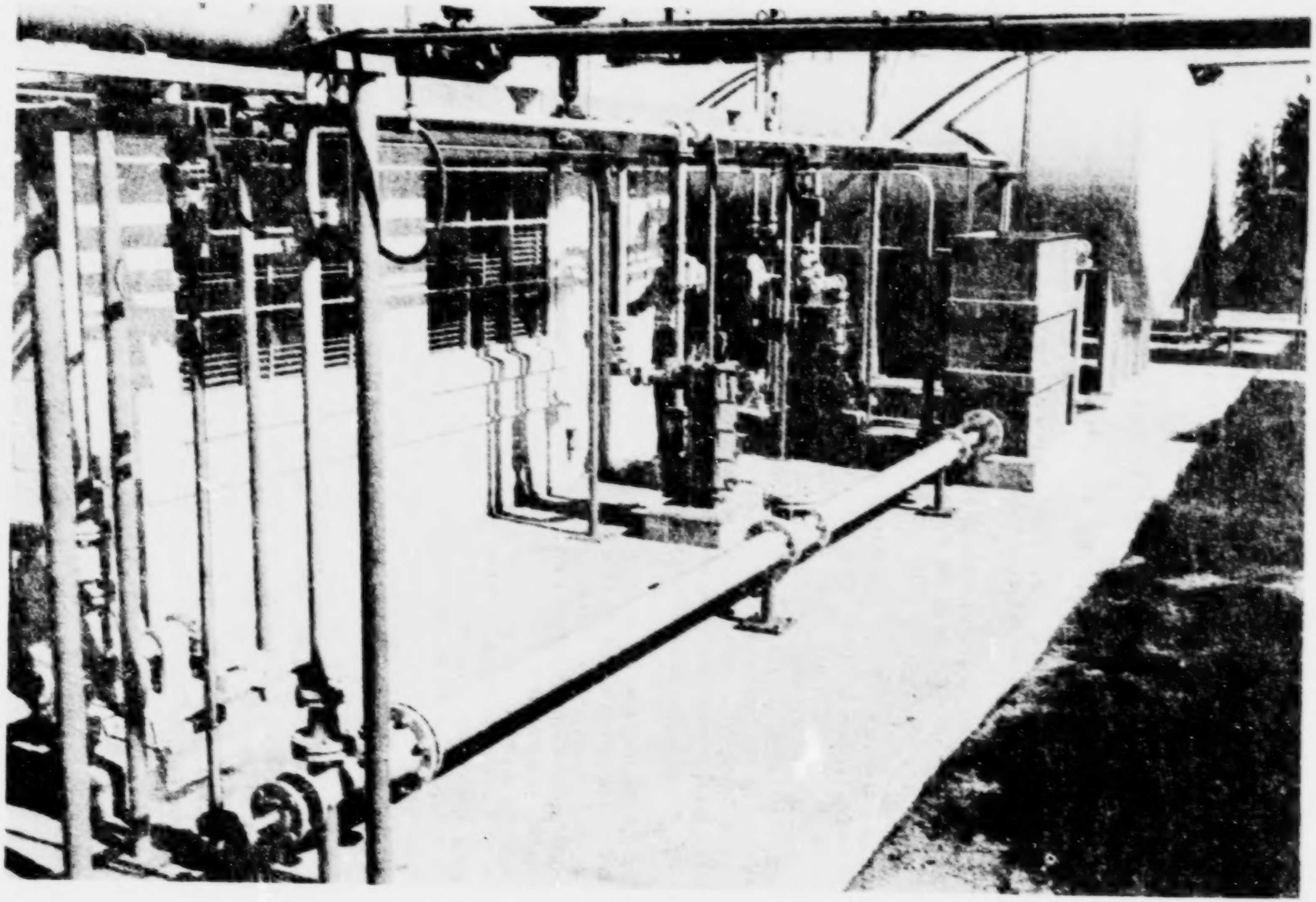


FIGURE 7.   AVERAGING TANK & REACTOR

has eliminated the requirement for either ice or refrigeration coils to be present inside the reactor. By utilizing reacted NaOCl and 14% NaOH as heat sinks at a relatively high temperature of 60°F, it was possible to use commercial air conditioning chillers rather than heavy duty industrial type refrigeration machines. This achieved a considerable saving in cost, both in equipment and installation. A second benefit of the relatively high temperatures of the heat sinks is that it will not be necessary to operate the chillers for approximately six months out of the year. During the winter months, a favorable temperature differential between the reacted material and the potable water distribution system will provide the needed refrigeration capacity. Thus, during that portion of the year when the temperature of the water in distribution mains is below 60°f, the cost of cooling will only be the cost of pumping and filtering water from the distribution mains. Utilizing water from the distribution system, the NaOCl plant can operate with a total connected load of 39 hp and demand load of 24 hp. These levels are approximately 25% of the total connected and demand load when the refrigeration chillers are in operation.

The NaOCl plant was designed to be completely outdoors with the exception of a small control house containing the control cabinet, a small laboratory for quality control and a desk for the chemist-operator. The NaOCl plant is located on one concrete slab 55 ft by 24 ft which contains all the equipment of the plant with the exception of the storage and unloading facilities. The NaOCl manufacturing plant is shown in Figure 8. To provide for receipt of the 50% NaOH and chlorine, an existing railroad siding was extended to the NaOCl manufacturing plant. The 50% NaOH unloading facilities are designed to unload a 10,000 gal. tank car of 50% NaOH in 50 min. The loading facility for the finished NaOCl has the capacity to load a 3,000 gal. tank truck in 15 min. These features are necessary to provide for quick loading and unloading during periods of high NaOCl usage.

With the entire plant outdoors, the requirement for ventilation to remove any escaping chlorine gas was eliminated. The outdoor location is considered adequate for plants in areas where the temperature rarely drops below freezing. However, if a plant of this type were to be constructed in the freezing zone, protection against freezing would have to be provided for the pneumatic control system.

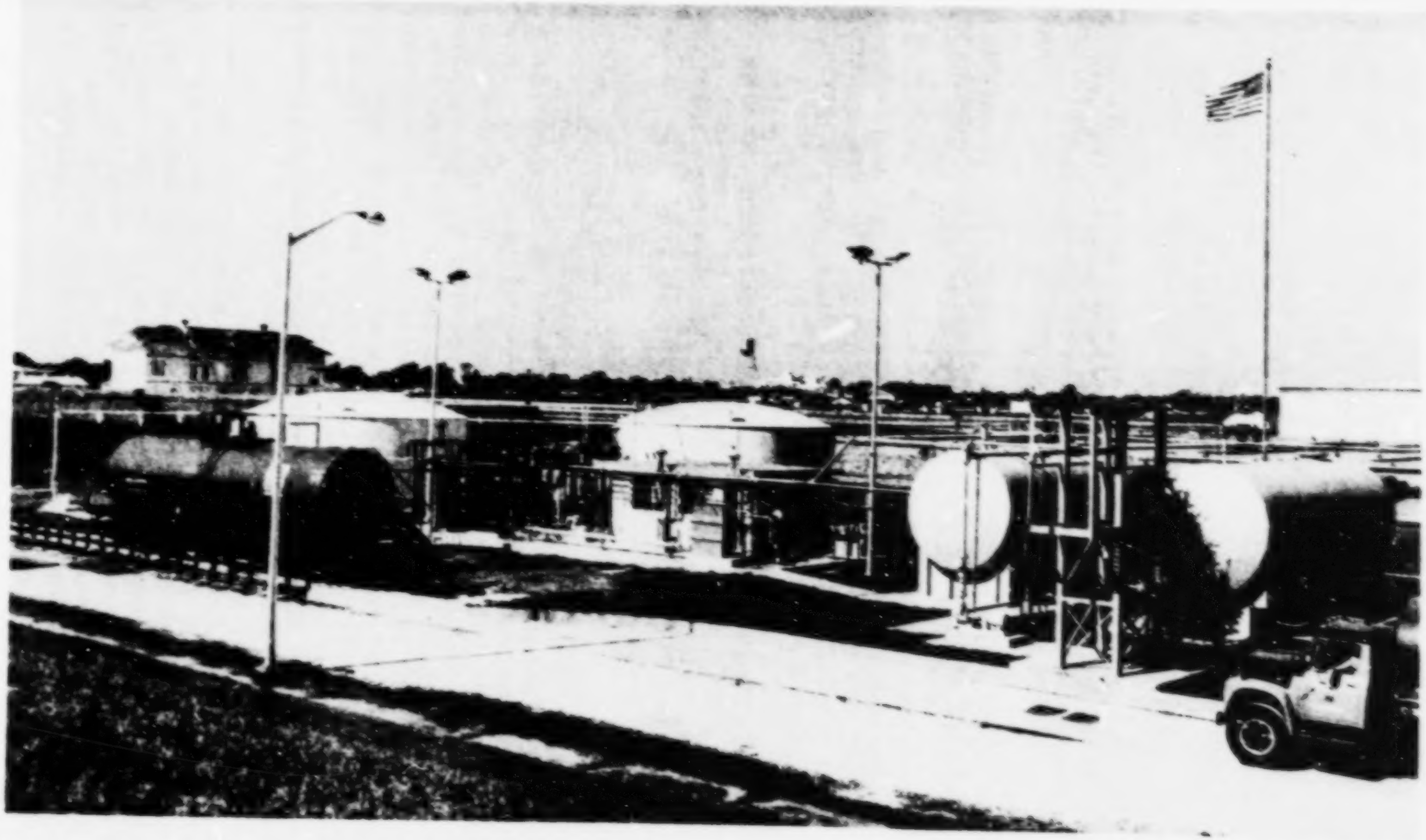


FIGURE 8. NaOCl MANUFACTURING PLANT - This view shows the entire NaOCl manufacturing plant. The Cl_2 supply car is in place on the railroad siding. The unloading facilities can be seen adjacent to the railroad track in front of the Cl_2 car. The NaOH storage tanks can be seen in the background. The finished NaOCl storage tanks are in the lower right of the picture.

Control System

The control system finally selected for this plant is shown on the process flow sheet in Figure 9. The control system basically consists of locally mounted sensing devices, electrical to pneumatic converters and pneumatically controlled actuators. The converters send signals to the control panel which is shown in Figure 10. From the control panel, transmitters send pneumatic signals to the control elements, such as valve positioners, to complete the loop. All flow meters are magnetic. Required information is recorded on four inch strip chart recorders mounted on the control panel. To provide sufficient resolution of the parameters during the manufacturing process, the speed of the strip chart recorder was selected at two in. per hour.

The main problem in designing the control system was finding equipment constructed from materials capable of withstanding the attack of the chemicals. As a general rule the control components, both valves and sensing devices, are constructed of the same material as that in which they are mounted. However, ORP cells are constructed of epoxy or PVC with silver and platinum electrodes. The temperature sensing probe in the NaOCl reactor is constructed of titanium. Level sensing devices of the bubble type were used throughout and utilized PVC piping for the bubble tube.

Operation

The NaOCl manufacturing plant is designed to be completely automatic and operated by a single chemist-operator. From the control panel, the chemist-operator can proportion the blending of 50% NaOH and water for reaction to the required NaOCl concentration. This proportion can be set from the control panel and is maintained by a ratio controller. In addition to the ratio controller, oxidation reduction potential (ORP) cells were originally used to compensate for variation in raw materials and/or finished product. The ORP was determined by the strength of the finished product and the excess alkalinity desired.

Normal practice in NaOCl manufacturing plants has been to control the chlorine feed and the excess alkalinity by measuring the ORP of the finished product. In batch type operations, an ORP sensing device is placed in the reaction tank to continuously measure the ORP of the reacting solution. Using this value of ORP, the plant operator varies the chlorine feed until the desired ORP value is attained. In

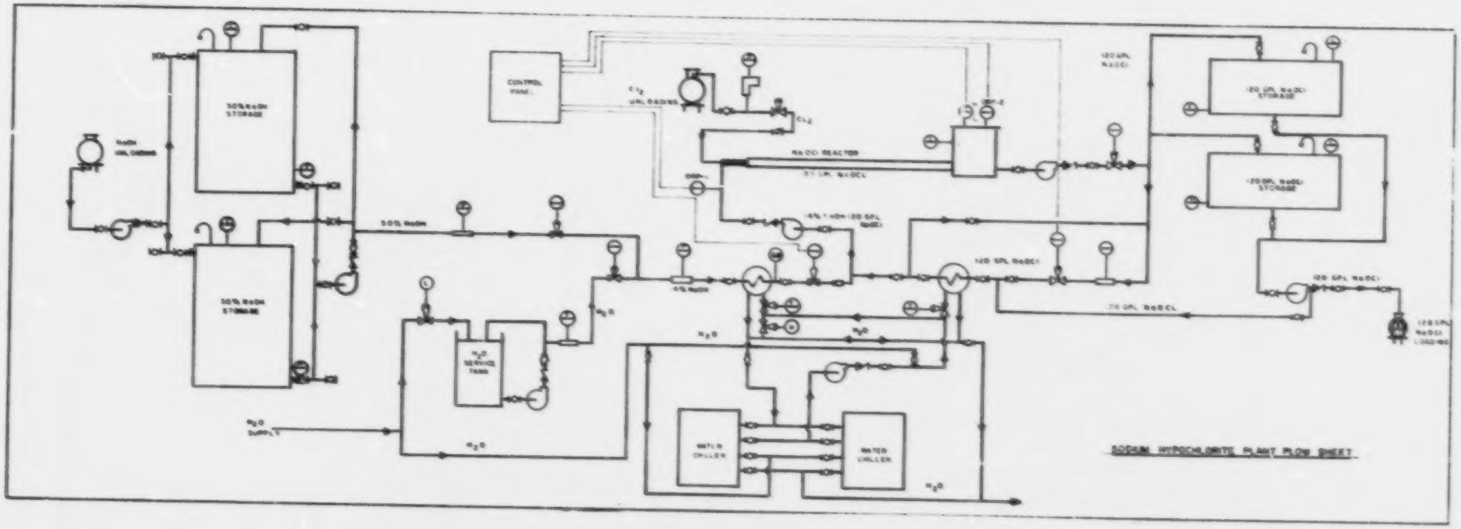

NaOH UNLOADING
50% NaOH STORAGE
50% NaOH STORAGE
CONTROL PANEL
Cl_2 UNLOADING
Cl_2
NaOCl REACTOR
57 GPL NaOCL
10% NaOH 120 GPL NaOCl
50% NaOH
4% NaOH
H_2O
H_2O SERVICE TANK
H_2O SUPPLY
H_2O
H_2O
WATER CHILLER
WATER CHILLER
H_2O
120 GPL NaOCl
120 GPL NaOCl
70 GPL NaOCL
120 GPL NaOCl STORAGE
120 GPL NaOCl STORAGE
120 GPL NaOCl
120 GPL NaOCl LOADING
SODIUM HYPOCHLORITE PLANT FLOW SHEET

FIGURE 9. FLOW SHEET - NaOCl MANUFACTURING PLANT

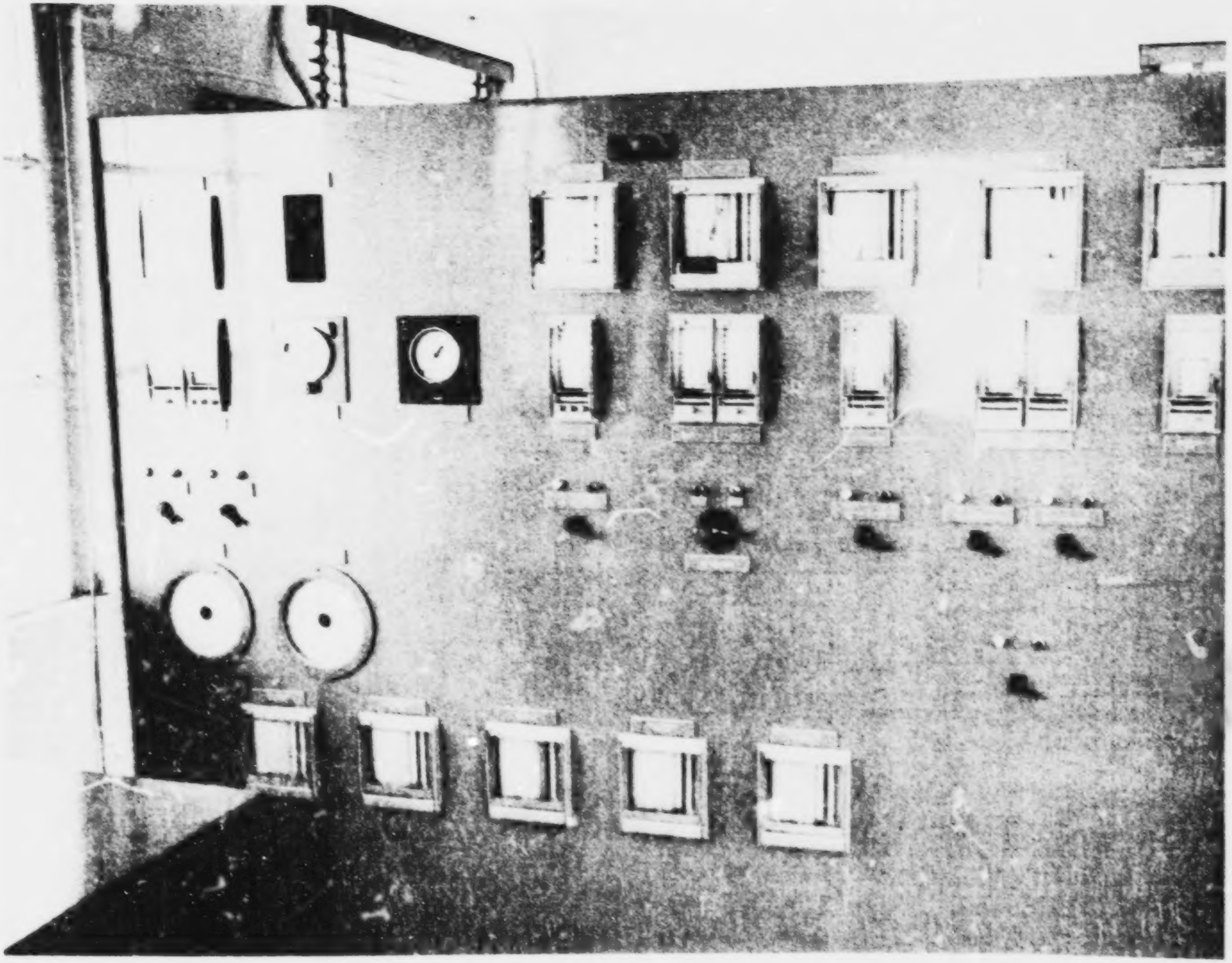


FIGURE 10. CONTROL PANEL AT $NaOCl$ MANUFACTURING PLANT

continuous manufacturing plants, the ORP of the finished product is monitored and the volume of chlorine feed is determined from this reading. This feedback use of ORP makes it possible to correct for over or under chlorination by changing the input chlorine feed. However, it does not indicate the presence of chlorate formation which is accompanied by an excessive temperature rise. Due to this important effect, reactor temperature was used to provide an overriding control for the ORP parameter. Also, rather than using ORP information only in a feedback loop, the possibility existed of using feedforward ORP information. This was accomplished by providing an ORP sensing device in the line carrying the mixture of cooled, recirculated NaOCl and 14% NaOH to sense the chlorine requirement of the incoming mixture. Thus, three systems of chlorine feed control by ORP were available.

1. The ORP of the finished product. (Feedback)
2. The ORP of the solution entering the reactor. (Feedforward)
3. The ORP of the solution entering the reactor in combination with the ORP of the finished product. (Feedforward control with feedback monitor and override).

A fourth method of chlorine control was also provided and is referred to as the ratio system. The ratio system controls the rate of chlorine addition by monitoring the flow rate of unreacted 14% NaOH.

In all four systems, the temperature of the reacted product is continuously monitored in the mixing tank. If the temperature in the reactor pipe exceeds a preset value of 86°F, both the chlorine valve and the 14% NaOH valve are immediately shut. This allows only cooled, recirculated NaOCl to enter the reactor and act as a heat sink until the temperature drops to 78°F. At this point, control will be returned to the chlorine control system set by the operator. A flow sheet of the final NaOCl manufacturing design is shown in Figure 9.

Shortly after exposure to high strength NaOCl, the ORP cell experienced rapid failure of the resin bonding the electrical cells to the body of the assembly. After several replacements, it was decided to abandon the ORP cells and to rely entirely on the ratio control system. This has presented no problem in the manufacture of high quality NaOCl. The temperature override was retained and provides adequate over chlorination and chlorate formation protection for the system.

MATERIAL SELECTION

Because of the chemical activity of NaOCl, the construction design was greatly affected by the process design. Many of the features of the process and construction design were dictated by the availability of materials which could withstand the highly corrosive products while being reasonable in cost. Many materials were studied for use in the reactor, NaOCl piping, and NaOCl storage facilities. Since the reactor was the most critical of the three components, materials for its construction were investigated first. The material finally selected would have to withstand the attack of both dry and wet forms of liquid and gaseous chlorine as well as NaOCl.

The only metals found to be resistant to the finished NaOCl were duriron, titanium, tantalum and platinum. Since the plant was designed to be operated outdoors, it would be subjected to the full range of normal ambient temperatures in New Orleans, 14°F to 95°F. Thus, the use of duriron was discarded because of its brittleness and sensitivity to temperature changes. Titanium, the least expensive of the remaining metals, was investigated thoroughly. However, tests showed that if the titanium oxide film which forms on the surface of the metal is removed and subsequently exposed to dry chlorine gas, the metal will flash, causing a fire. For this reason, titanium was discarded as a material for the reactor. Tantalum and platinum were eliminated from consideration due to their cost.

Several plastics, both of the pure and "fibrous" glass varieties, were investigated. It was found that the fibrous varieties were dependant on the quality of the resin binding the glass for resistance to chemical attack. It is also difficult to manufacture this material with reasonable assurance of quality. The first pure plastic investigated was polyvinlychloride (PVC) which is commonly used to contain and transport NaOCl. However, this material is very brittle and has low beam strength. Thus, PVC was not deemed a suitable material for the reactor. After futher investigation, polyvinyllidene fluoride (kynar) lined steel pipe was selected for use as the reactor. The reactor is shown in Figure 11. It consists of a polyvinlyidene fluoride sparger tube carrying the liquid chlorine into a polyvinylidene fluoride lined pipe where the chlorine is discharged into the mixture of precooled NaOCl and 14% NaOH. At the design rates of flow, complete mixing should be achieved in the reactor almost immediately. However, to provide additional mixing and to insure against

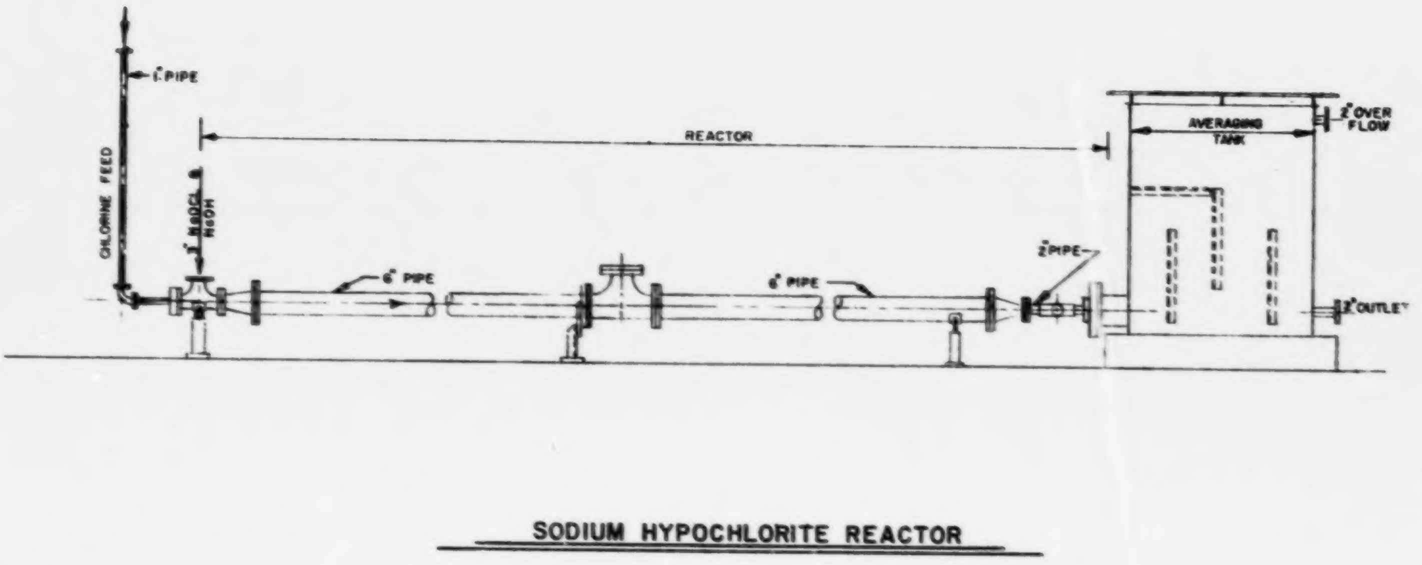

1" PIPE
CHLORINE FEED
1" NaOCl & NaOH
REACTOR
6" PIPE
6" PIPE
2" PIPE
AVERAGING TANK
2" OVER FLOW
2" OUTLET
SODIUM HYPOCHLORITE REACTOR

FIGURE 11. NaOCl REACTOR

any gaseous chlorine passing through without reacting, a perforated baffle was placed at the midpoint of the reactor tube. At a flow of 51 gal./min, retention time in the reactor tube is 64 sec. The reacted material then passes into an averaging tank which provides a liquid head of 8 ft to insure against any unreacted chlorine reaching the surface and discharging into the atmosphere. Polyvinylidene fluoride lined pipe was used for all NaOCl lines and 14% NaOH lines. Ordinary steel pipe was used to carry water from the water distribution system to the NaOCl plant. The materials used for construction of the major plant components are listed in Table 3.

CONSTRUCTION OF NaOCl MANUFACTURING PLANT

The construction of the NaOCl manufacturing plant took approximately 10 months. From a mechanical standpoint, the NaOCl manufacturing facility was a relatively simple plant to construct. Once the contractor gained experience in making up the lined pipe joints, piping erection was speeded up considerably. The other phases of the construction proceeded smoothly.

Preliminary testing of the NaOCl manufacturing plant began on April 1, 1969 in accordance with the startup schedule. The NaOCl plant was first operated utilizing only water throughout the plant to check for leaks and test all pumps, control valves, and control functions. During this period all automatic controllers were placed on their set points and tested. This initial procedure was accomplished during the first two weeks of April, 1969. After the NaOCl plant was completely tested by the utilization of water, the first tank of 50% NaOH was ordered and received. The startup procedures called for utilizing only 50% NaOH in the plant until all control functions pertaining to this material were operating perfectly. During this period the NaOCl plant was operated to dilute 50% NaOH to 14% NaOH. The 14% NaOH passed through the reactor to a storage tank. During this time approximately 12,000 gal. of 14% NaOH were prepared. When all control functions were operating properly, the plant was shut down and thoroughly cleaned. On May 21, 1969, the NaOCl plant first utilized chlorine and 14% NaOH to prepare finished NaOCl. Preliminary testing continued during the summer of 1969. During the period of the project, the NaOCl plant has operated satisfactorily and was able to produce its design quality of high strength NaOCl. NaOCl of strengths as low as 100 gpl and as high as 150 gpl were prepared to test the flexibility of plant design.

TABLE 3

NaOCl PLANT EQUIPMENT AND MATERIAL LIST

ITEM	MATERIAL & CONSTRUCTION
50% NaOH Storage Tanks	Welded Carbon Steel with epoxy interior lining.
50% NaOH Pumps	All iron, centrifugal
50% NaOH Piping	Seamless Carbon Steel, Sch. 40
50% NaOH Valves	SS ball valves
H_2O Pumps	All iron, centrifugal
H_2O Piping	Seamless Carbon Steel, Sch. 40
H_2O Valves	SS ball valves
14% NaOH Piping	Polyvinylidene fluoride lined carbon steel.
14% NaOH Heat Exchangers	Plate Type - 304 S.S.
14% NaOH Valves	SS ball Valves
Cl_2 Piping	Seamless Carbon Steel, Sch. 80
Cl_2 Valves	SS Ball Valves
NaOCl Pumps	Polypropylene lined Steel, centrifugal
NaOCl Piping	Polyvinylidene fluoride lined carbon steel.
NaOCl Reactor	Polyvinylidene fluoride lined steel, polyvinylidene - solid PVC lined fibrous glass
NaOCl Heat Exchanger	Plate Type - Titanium
NaOCl Valves	Teflon lined, SS ball valves
NaOCl Tanks	Welded Carbon Steel, rubber lined
Control Valves	
H_2O	Cast Steel, ported
NaOH	Cast Steel, ported
NaOCl	Polyvinylidene fluoride lined Saunders Diaphragm
Electric Motors	Epoxy encapsulated
Electric panels, motor controllers, push buttons, pilot lights, etc.	Standard NEMA construction in Cu. free, cast Al housings.
Refrigeration Equipment	Standard Air Conditioning Type Packaged Chilled Water Systems

Evaluation of NaOCl Manufacturing Plant

The NaOCl plant has demonstrated its capability to manufacture a consistant product of high quality without discharging gaseous chlorine to the atmosphere. With the unpressurized reactor, even over chlorination has proven to be more of an annoyance rather than a major accident. On July 19, 1969, over chlorination occurred while setting the ORP control system. However, rather than the usual sudden release of chlorine to the atmosphere, only a slight bubbling on the surface of the averaging tank was noted. Over chlorination was not confirmed until a sample of NaOCl had been titrated. As the temperature in the reactor increased, the temperature override shut down the process and prevented further chlorine from entering the reactor. It is felt that this malfunction justified the design of the reactor to operate at atmospheric pressure.

Some difficulty has been observed in obtaining proper mixing in the averaging tank located at the end of the reactor. In subsequent designs, this tank should be enlarged so that an adequate head of finished material is maintained and complete mixing in the averaging tank is achieved.

Several problems were encountered with the handling of the finished NaOCl. The ORP cells that measure the strength of the chemicals failed due to the action of NaOH and NaOCl on the epoxy lining of the cell. Due to this failure, the plant has been run by the chemist-operator using the ratio control system. There have been several failures of the lining in the reactor averaging tank and two failures of the reactor pipe. These problems were traced to stresses caused by vibrations generated in the mixing of the chemicals. The averaging tank was replaced with a polyethylene tank designed by Sewerage and Water Board personnel. The replacement tank has performed satisfactorily. The kynar lined reactor pipe was replaced free of charge by Resistoflex.

One problem that remained intractable was the continuing failure of the polypropylene lined NaOCl pumps manufactured by the Saran Lined Pipe Company. With intermittent operation, the NaOCl ramaining in the system deteriorates and crystals form on the pump seal faces. On subsequent operation, the seals are damaged and NaOCl reaches unlined sections of the pump shaft. Rapid failure of the pump follows. Tests were conducted using a teflon seal in place of the carbon seal and operating life was increased from two to six months. Additionally, the polypropylene lining covering the impeller and casing of the pump has failed. It is possible that the

TABLE 4

AGING CHARACTERISTICS OF STORED NaOCl

PART A Average Daily Decrement in NaOCl Strength [gram/l/day]

Concentration [gram/l]	Jan - Mar	Apr - June	July - Sept	Oct - Dec	Avg.
90 - 100	.2	.57	1.1	.56	.61
80 - 90	.36	.32	.84	.76	.59
70 - 80	.11	.33	.33	.64	.35
60 - 70	.3	.43	.84	.21	.44
50 - 60	.3	.43	.34	.41	.37
40 - 50	--	.47	.31	.26	.35
20 - 40	--	.1	.1	--	.10

PART B Approximate Half-Life of Stored NaOCl

Storage Period	Initial Conc. [gram/l]	Final Conc. [gram/l]	Days stored	Approx. Half Life
Mar 13 - Aug 2	92.9	52.5	133	149
Mar 13 - Aug 2	94.3	41.1	133	130
Apr 17 - Aug 2	96.5	53.2	107	120

NaOCl attacks the lining along mechanical and thermal stress lines. Previous experience with polypropylene lined pumps indicates that they can be maintained for long periods of time during continuous operation in low strength NaOCl environments. The difficulties encountered with the polypropylene lined pumps are due to the highly intermittent usage pattern and high strength of the NaOCl. The use of all titanium pumps had been contemplated at the initiation of the project, but the cost was prohibitive ($6,000/pump compared to $500/pump). At present, it appears that flushing of the entire system, piping and pumps, between periods of use or replacement of the pumps as they fail are the only solutions.

The aging characteristics of the manufactured NaOCl in the field are given in Table 4. Table 4, Part A gives the average daily decrease in strength as a function of NaOCl concentration. These figures are based on weekly sampling of stored NaOCl at the pumping stations. Table 4, Part B, is the field half life (i.e. time for the concentration to reach one half its initial value) of the NaOCl as stored in the tanks and exposed to ambient conditions. The approximate half life was calculated by using the average daily decrement. The values seem comparable to NaOCl aging properties reported in the literature (33) when the range of ambient temperatures in New Orleans is considered during the storage period. (60°F - 98°F air temperature)

SECTION VI

TRANSPORTATION EQUIPMENT

The design of the treansportation equipment was based on the necessity to replace NaOCl as it was utilized during the worst five day period at each pumping station. From a consideration of the pumping characteristics of the pumping stations and chlorine demand of the storm water, the original requirement was one of being able to transport 40,000 gals. of NaOCl to each of three pumping stations during a five day period. DPS #7, originally slated to feed 40,000 gals. of chlorine, was later redesigned to feed NaOCl.

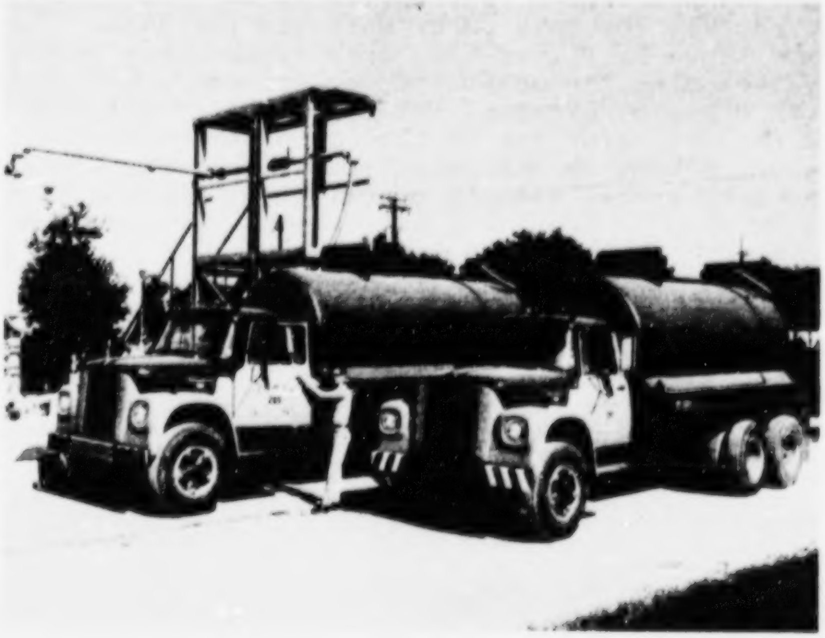


FIGURE 12. NaOCl TRANSPORT TRUCKS

Louisiana has a legal limit of 50,000 lbs for any over the road vehicle. A study of available trucks indicated that approximately 3,000 gals. of finished NaOCl would result in a gross vehicle weight approaching 50,000 lbs. A survey of the routes that can be taken to the pumping stations indicated that, at most, three trips per eight hour shift could be made by one truck. Assuming 100% availability, a capacity to deliver 22,000 gals. per 24 hrs would be needed. Based on the requirement for replenishment at the feeding facilities, one truck would have sufficed. Since 100% availability of automotive equipment cannot be assumed, two rubber lined steel tank trucks were purchased. The trucks were standard heavy duty trucks with reinforced chassis to carry the heavy loads. The storage tank on each truck if 5 ft 10 in. in diameter and 16 ft 8 in. long with a capacity of 3,000 gals. The tank is made of steel lined with a three-ply, semi-hard, rubber lining. The tank is designed for compressed air unloading. The air compressors have sufficient capacity to unload a truck in approximately 30 minutes. The tank is equipped with ladders, walkways and a manhole and meets the requirements of the Interstate Commerce Commission cargo tank specification #M-312 MS. The trucks are tandem trucks (International Harvester) utilizing a single chassis for both power unit and the tank. The trucks are shown in Figure 12. Both trucks have been used extensively during the period of the program. The trucks have shown signs of external deterioration in the form of rust and peeling paint due to the harsh environment. However, the lining on the interior of the truck tanks is sound and both trucks were in operation at the end of the project.

SECTION VII

SODIUM HYPOCHLORITE STORAGE FACILITIES

STORAGE TANK DESIGN

The major problem of the project was presented by the storage and handling of 160,000 gals. of 120 gpl NaOCl both at the NaOCl manufacturing plant and at the pumping stations. While there are many materials listed as being capable of containing 120 gpl NaOCl, it was discovered that very few had been used for long term storage of NaOCl at this concentration. In addition, many materials were not recommended for outdoor use. Since NaOCl was to be stored in residential or semi-commercial areas, the safety of adjacent properties and residences had to be given the highest priority. In analyzing the linings of NaOCl storage tanks then currently in use, it was found that previous experience had been with low strength NaOCl solutions for extended periods of time or high strength NaOCl solutions for short periods of time. Also, thorough flushing of the storage facility between periods of use was the rule.

MATERIAL SELECTION

General

Since the above conditions could not be met, the investigation was widened to include all materials capable of withstanding NaOCl attack. Among the materials and types of construction available were the following:

1. Rubber lined steel.
2. Solid plastics.
3. Concrete tanks with collapsible liners.
4. Fibrous glass reinforced polyester materials.
5. Polyethylene lined steel.

Each material and construction method was investigated with respect to three main considerations: (1) a tank construction design which would prove resistant to the highly corrosive NaOCl for long periods of time, (2) because of the limited space available at several of the pumping stations, a multitude of small storage tanks could not be tolerated, and (3) it was not desirable to have NaOCl storage tanks which would exceed the height of any surrounding residences. These limitations were met by using two, 20,000 gal. horizontal, cylindrical, steel storage tanks at each pumping station and at the NaOCl manufacturing plant. Since tanks of this size were almost unheard of for NaOCl storage, each of the available construction methods and materials was studied to determine their adaptability to constructing NaOCl storage tanks of this size.

Rubber Lined Steel

While there was more experience in the use of rubber lined steel tanks for storage of high strength NaOCl, it was found that their performance had been very erratic. Indeed, the suppliers of rubber lined steel tanks readily admitted that the integrity of the tank was dependent on the workmanship used in the application of the rubber liner to the steel. Tanks storing 80 gpl NaOCl, used as bleach in pulp mills, indicated some tanks had useful lives of 15 to 17 years. Other tanks lined with the same material, applied by the same personnel, lasted only six months to two years. The manufacturers also admitted that the 15,000 volt spark test was no guarantee of a proper bond between the rubber lining and the steel. Since tanks holding 20,000 gals. of NaOCl must be lined with several sheets of rubber, each containing several joints, the possibility of having an incompletely sealed tank is high. However, NaOcl storage tanks lined with rubber had performed very capably in many cases.

Solid Plastic

Tanks made of solid plastic such as PVC or polyester resins were also investigated. However, the low beam strength of these materials made their construction in these sizes impractical.

Lined Concrete Tanks

The use of concrete tanks with collapsible liners was also investigated because concrete is known to be fairly resistant to high strength NaOCl. However, the tanks were very difficult to repair if failure occurred and this type of construction was deemed unsuitable.

Fibrous Glass Reinforced Polyester

Another material which had been used with some success to store high strength NaOCl was fibrous glass reinforced polyester. Investigations again brought out the importance of good workmanship in the proper fabrication of these tanks. The basic method is to construct a fibrous glass tank of sufficient thickness to provide structural integrity and then applying a NaOCl resistant resin to the interior. However, it was found that due to the unequal thermal coefficient of expansion between the pure resin liner and the fibrous glass outer shell, a crazing of the inner liner occurred. This resulted in rapid failure of the tank. Since rather wide temperature fluctuations were expected, this method of construction was deemed unsuitable.

Polyethylene Lined Steel

The final method of construction considered was a steel tank lined with polyethylene sheets. This material has been used with some success in containing high strength NaOCl as well as other very corrosive materials. The only drawback of this particular method of lining appeared to be an uneven distribution of thermal stress between the steel tank and the polyethylene lining. This uneven matching of thermal coefficients of expansion causes "bubbles" to appear in the lining. However, no difficulties are encountered as long as the "bubble" does not destroy the continuity of the welds at the edge of the individual sheaths of lining.

Final Selection and Evaluation

Based on this data, the final selection resulted in four tanks lined with white natural rubber (DPS #4 and St. Charles), four tanks lined with flexible hard rubber (DPS #3 and plant), and two tanks lined with polyethylene (DPS #7). The storage tanks were in operation for approximately four years under extreme temperature and NaOCl concentration conditions. During this period no failures of any tanks have occurred. Additionally, the linings of all tanks appear to be sound as of the time of the final report.

SECTION VIII

NaOCl DISINFECTION FACILITIES

GENERAL

Once the NaOCl has been manufactured at the plant and stored at the pumping stations, a system was needed to deliver the NaOCl to the storm water on a demand basis. The basic concept of feeding NaOCl to bacterially polluted storm drainage water is the same at all four pumping stations involved in the program.

However, there are slight differences in the manner in which the storm water reaches, is disinfected, and leaves each pumping station. The points of application at each station and the physical differences are as follows:

1. DPS #3 - NaOCl is fed to the storm water in the discharge bay. This occurs prior to a constriction in the outfall canal. The constriction is used to provide mixing of the disinfectant and storm water.
2. DPS #4 - NaOCl is added to the storm water in the suction bay and depends on the pumps of the station to provide mixing of the disinfectant and storm water.
3. DPS #7 - NaOCl is added in the suction bay just prior to the pumping station. The pumps at the station provide complete mixing of the disinfectant and storm water.
4. St. Charles DPS - NaOCl is added to the storm water through a submerged, perforated pipe at the entrance of a large, concrete lined, reaction basin which has a retention time of 22 to 86 minutes. The reaction basin is on the suction side of the pumps and provides a chamber for mixing of the NaOCl and storm water.

DPS #3

DPS #3 is located on the London Avenue Canal 3.03 miles from Lake Pontchartrain. The canal is covered to the station and open from the station to the lake. The station is equipped with five pumps having capacities from 550 cfs to 1,000 cfs with a total capacity of 4,100 cfs. Low volume pumpages arriving at the station are pumped into the Florida Avenue Canal - Bayou Bienvenue system while high volume pumpage is directed to Lake Pontchartrain.

Disinfectant storage at the station consists of two, 20,000 gal. rubber lined steel tanks. The NaOCl feeding system employs two polypropylene lined centrifugal pumps, each having a capacity of 160 gal./min against a 90 ft TDH. The installation at DPS #3 is shown in Figure 13. The disinfectant feed pumps empty into a common discharge header which is carried underground to the outfall canal. At the outfall canal, the disinfectant line comes above ground and is carried on a timber trestle across the outfall canal. Once the feed line reaches the trestle, it is equipped with nozzles which discharge NaOCl into the water across the full width of the outfall canal. The disinfectant feed line installation is shown in Figure 14. At the point of discharge, the London Avenue Canal is 160 ft side. At a point 220 ft downstream, the canal narrows to 95 ft and remains at this width for 17,050 ft before widening again to 130 ft. Thus, a constriction in flow occurs which might have provided sufficient turbulence for complete mixing of the disinfectant and storm water. This assumption was not proven during the program as channeling of the water took place rather than turbulent mixing. The channeling resulted in inadequate mixing of the storm water and disinfectant. Very high levels of chlorine residual (Cl_2R) occurred in parts of the canal, while in other portions no residual was found. This is in contrast to the excellent mixing provided by the pumps at those stations where the disinfectant is added prior to pumping. If possible, the feed point should be moved at this and subsequent installations to a point prior to pumping. A flow sheet of the feeding and sampling facilities at DPS #3 and #4 is shown in Figure 15.

DPS #4

DPS #4 is located on the east side of the London Avenue Canal at Prentiss Avenue, 1.09 mi from Lake Pontchartrain. All

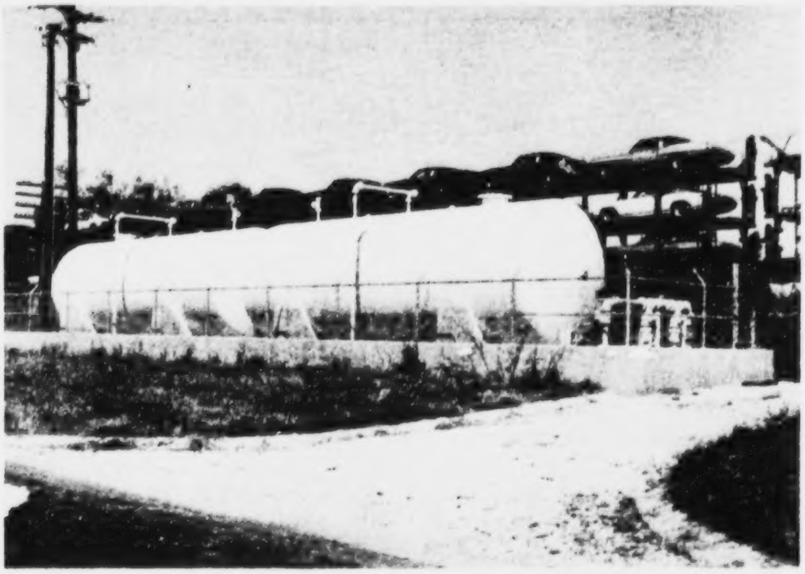


FIGURE 13. NaOCl STORAGE AND PUMPING FACILITIES, DPS #3

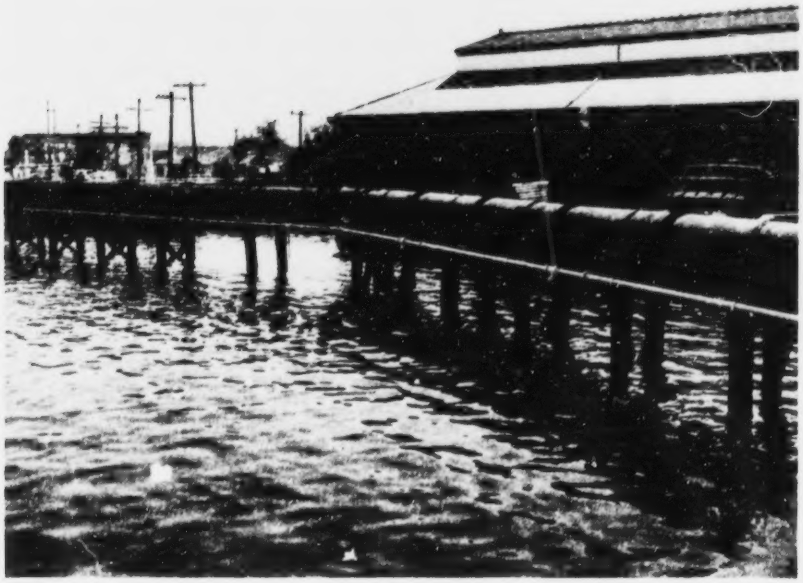


FIGURE 14. NaOCl SUPPLY HEADER AND DISCHARGE NOZZLES

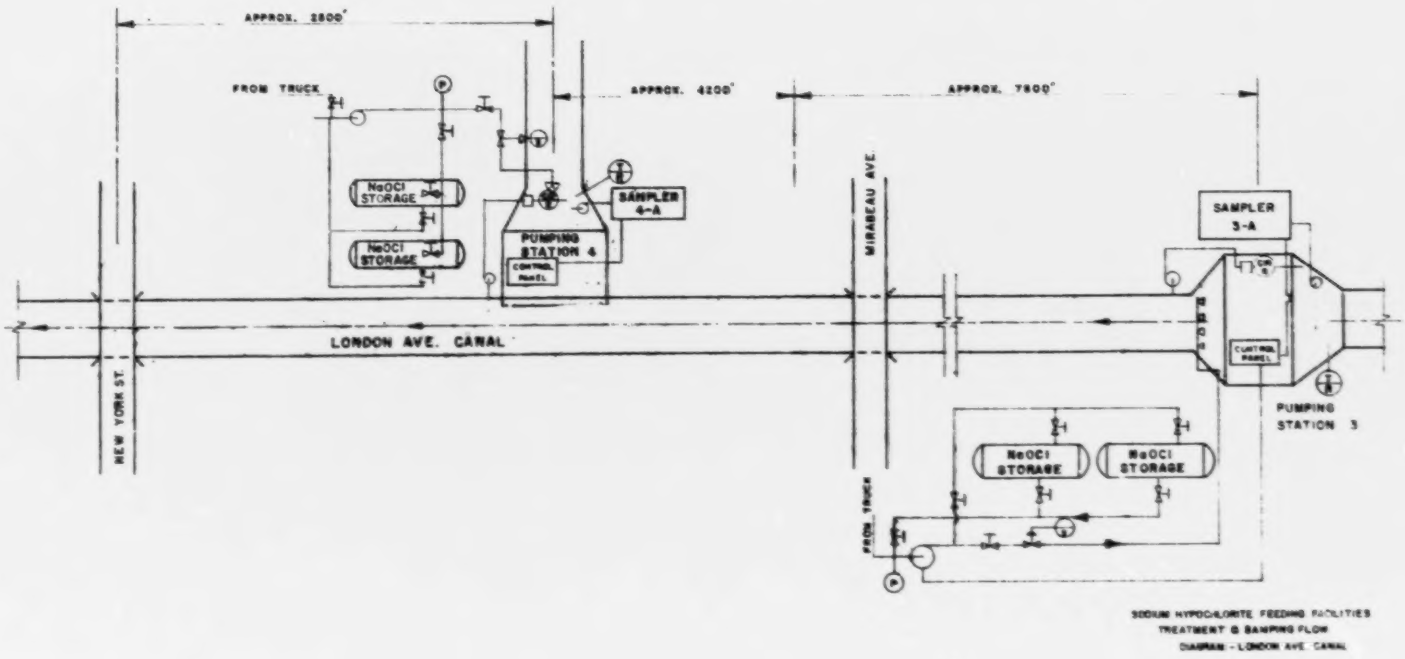

APPROX. 2800'
APPROX. 4200'
APPROX. 7800'
FROM TRUCK
NaOCl STORAGE
NaOCl STORAGE
PUMPING STATION 4
CONTROL PANEL
SAMPLER 4-A
NEW YORK ST.
MIRABEAU AVE.
LONDON AVE. CANAL
SAMPLER 3-A
CONTROL PANEL
PUMPING STATION 3
NaOCl STORAGE
NaOCl STORAGE
FROM TRUCK
SODIUM HYPOCHLORITE FEEDING FACILITIES
TREATMENT & SAMPLING FLOW
DIAGRAM - LONDON AVE. CANAL

FIGURE 15. DPS #3 & #4 - FLOW SHEET NaOCl FEEDING FACILITIES

influent lines to the canal are covered. The station is equipped with five pumps having capacities from 300 cfs to 1,100 cfs, with a total capacity of 3,900 cfs. A unique feature is the pumping of low volume storm drainage to DPS #3 and thereby into the Florida Avenue Canal - Bayou Bienvenue System which ultimately discharges into Lake Borgne, a large body of water east of New Orleans.

At DPS #4, two covered canals enter the suction bay. One canal has an invert 4 ft lower than the other. The disinfectant feeding facilities at DPS #4 are similar to those at DPS #3 except that application of the NaOCl is on the suction side of DPS #4, and thus, prior to pumping of the storm water. The disinfectant storage and feeding system consists to two, 20,000 gal., rubber lined steel tanks and two polypropylene lined centrifugal pumps. The disinfectant is fed to the storm water from a pipe located on the divider wall of the two incoming feeder canals (Fig. 16). A flow sheet of the feeding and sampling facilities at DPS #4 is shown in Figure 15.

Reproduced from best available copy.

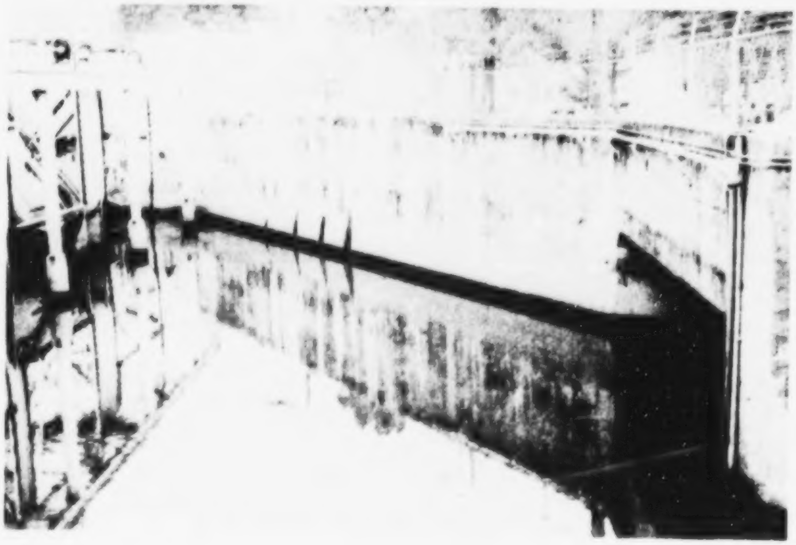


FIGURE 16. DPS #4 NaOCl FEEDLINE

DPS #7

DPS #7 is located on the Orleans Avenue Canal, 2.43 miles from Lake Pontchartrain. Canals on the inlet side are covered while the outfall canal is entirely open. The Orleans Avenue Canal is leveed to protect the adjacent land areas from flooding. DPS #7 is located in City Park and is one of the oldest stations in the system. It was originally constructed in 1895. Originally, it had been intended to feed chlorine at DPS #7 rather than NaOCl in order to provide an evaluation of the two disinfection methods. However, the feeding and storage of chlorine at DPS #7 was abandoned due to safety considerations. Once the decision had been made, storage and feeding facilities for NaOCl similar to those at DPS #3, #4, and St. Charles were installed. The NaOCl storage and feeding facility consists of two, 20,000 gal., polyethylene lined steel tanks for NaOCl storage and two polypropylene lined disinfectant feed pumps. A flow sheet of the sampling and feeding facilities is shown in Figure 17.

ST. CHARLES PUMPING STATION

The NaOCl feeding facilities at the St. Charles pumping station are unique. The discharge of this station is located approximately 1,600 ft from Lake Pontchartrain. The usual pattern of closed canals on the suction side of the pumping station with open outfall canals on the discharge canal has been reversed. Since this pumping station drains an area which is presently being developed, drainage canals leading to it have been designed as storage facilities for storm water runoff prior to its being pumped. Since additional time was available to pump the storm water, the station was built with less capacity than the pumping stations in the older parts of town. Thus, a relatively long period of time is available for contact between the point of entry of the reaction basin. NaOCl is fed to the storm water entering a reaction basin approximately 1,600 ft prior to pumping. This eliminates the problem involved with chlorinated water being discharged to the lake and its possible influence on the biota in the vicinity of the discharge. To provide sufficient retention time for complete reaction of NaOCl and storm water at different rates of pumpage, it was necessary to provide a reaction basin, measuring 1,673 ft by 98.5 ft by 11 ft, at the station. A reaction basin of this size provided between

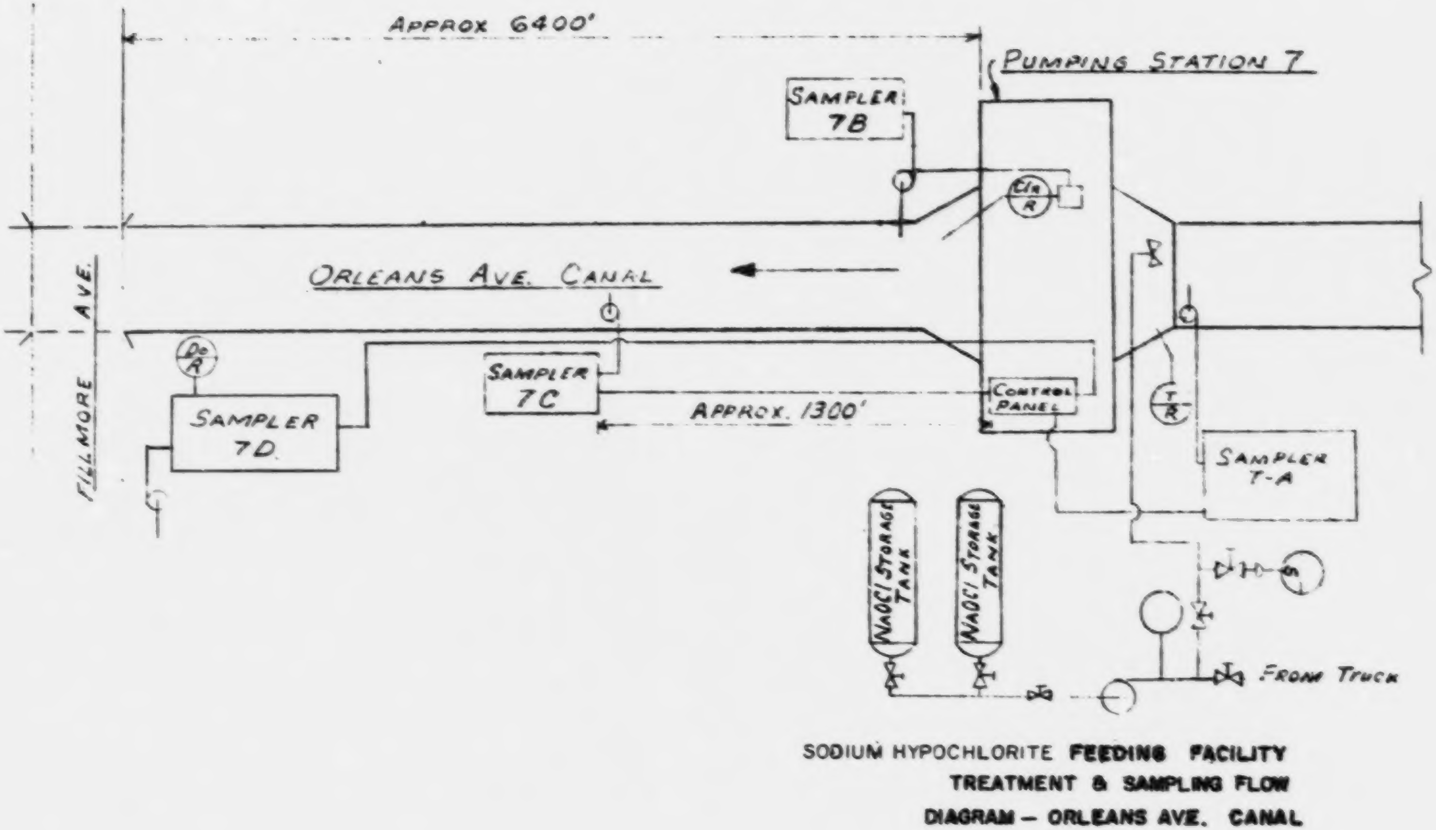

APPROX 6400'
PUMPING STATION 7
SAMPLER 7B
Cl₂ R
ORLEANS AVE. CANAL
FILLMORE AVE.
DO R
SAMPLER 7C
SAMPLER 7D
APPROX. 1300'
CONTROL PANEL
T R
SAMPLER T-A
NaOCl STORAGE TANK
NaOCl STORAGE TANK
FROM TRUCK
SODIUM HYPOCHLORITE FEEDING FACILITY
TREATMENT & SAMPLING FLOW
DIAGRAM – ORLEANS AVE. CANAL

FIGURE 17. DPS #7 FLOW SHEET NaOCl FEEDING FACILITIES

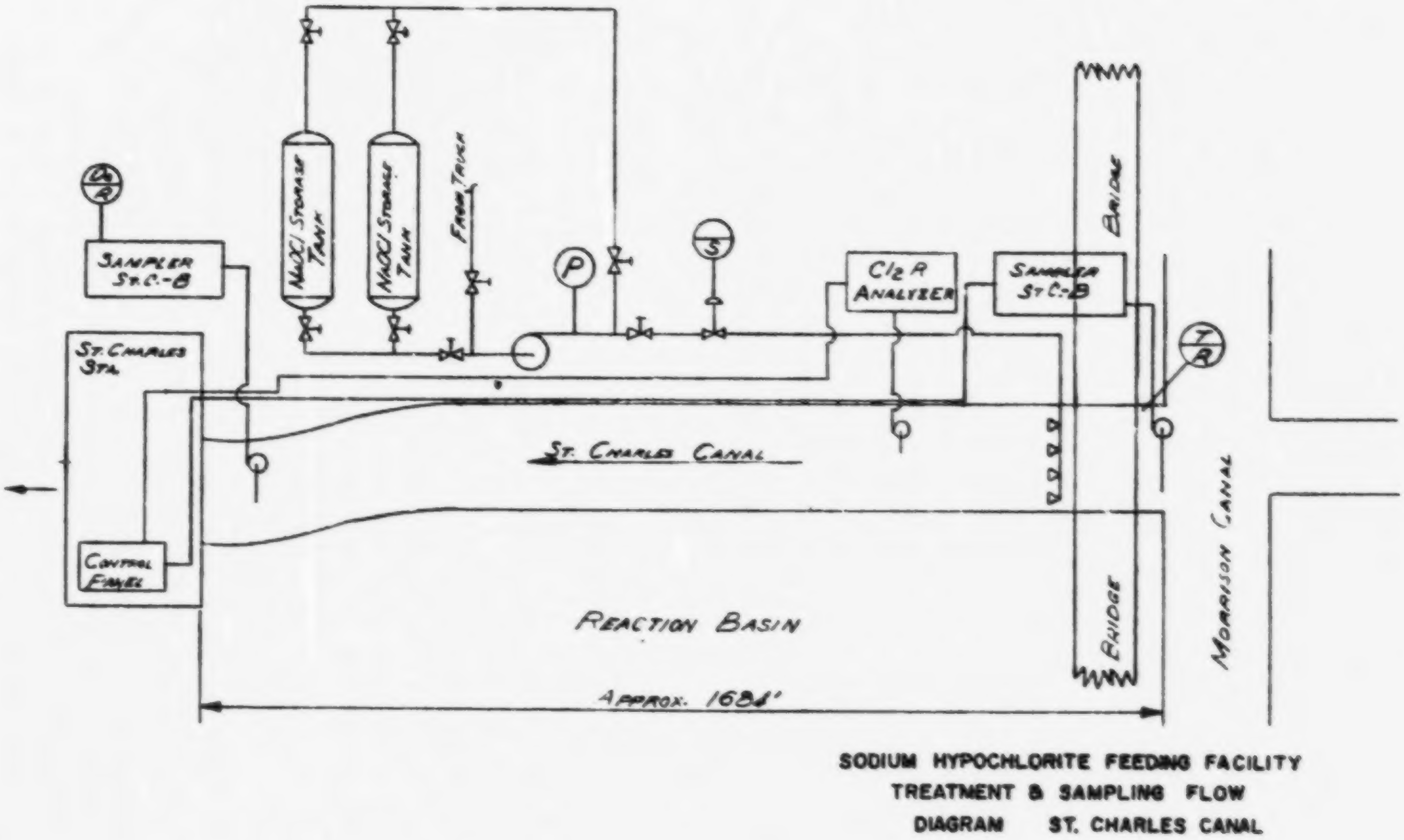
22 and 86 minutes retention time based on the pumping rate of the station. Soil conditions and the size of the reaction basin required that it be completely lined with concrete. NaOCl is fed under water at the inlet of the reaction basin as shown on the treatment and sampling flow sheet (Fig. 18). For safety purposes, NaOCl storage and feeding facilities are located at the station with NaOCl being pumped to the point of application. One interesting aspect of the reaction basin design was the inclusion of relief holes in the bottom to equalize water pressure. The relief holes eliminated the need for support and anchor piling which would have been necessary to prevent the reaction basin from rising out of the ground during drought periods. A cross section of the reaction basin is shown in Figure 19 along with a general plan view of the area. A view from the St. Charles pumping station to the point of disinfectant feed is shown in Figure 20.

The St. Charles DPS is equipped with four, 250 cfs pumps. The NaOCl feeding facilities are similar to those at the other pumping stations. Two, 20,000 gal. rubber lined steel tanks store the NaOCl and two polypropylene lined pumps are utilized to pump the disinfectant. Each polypropylene lined pump has a capacity of 40 gal./min against a 50 ft TDH.

RESIDUAL CHLORINE ANALYZERS

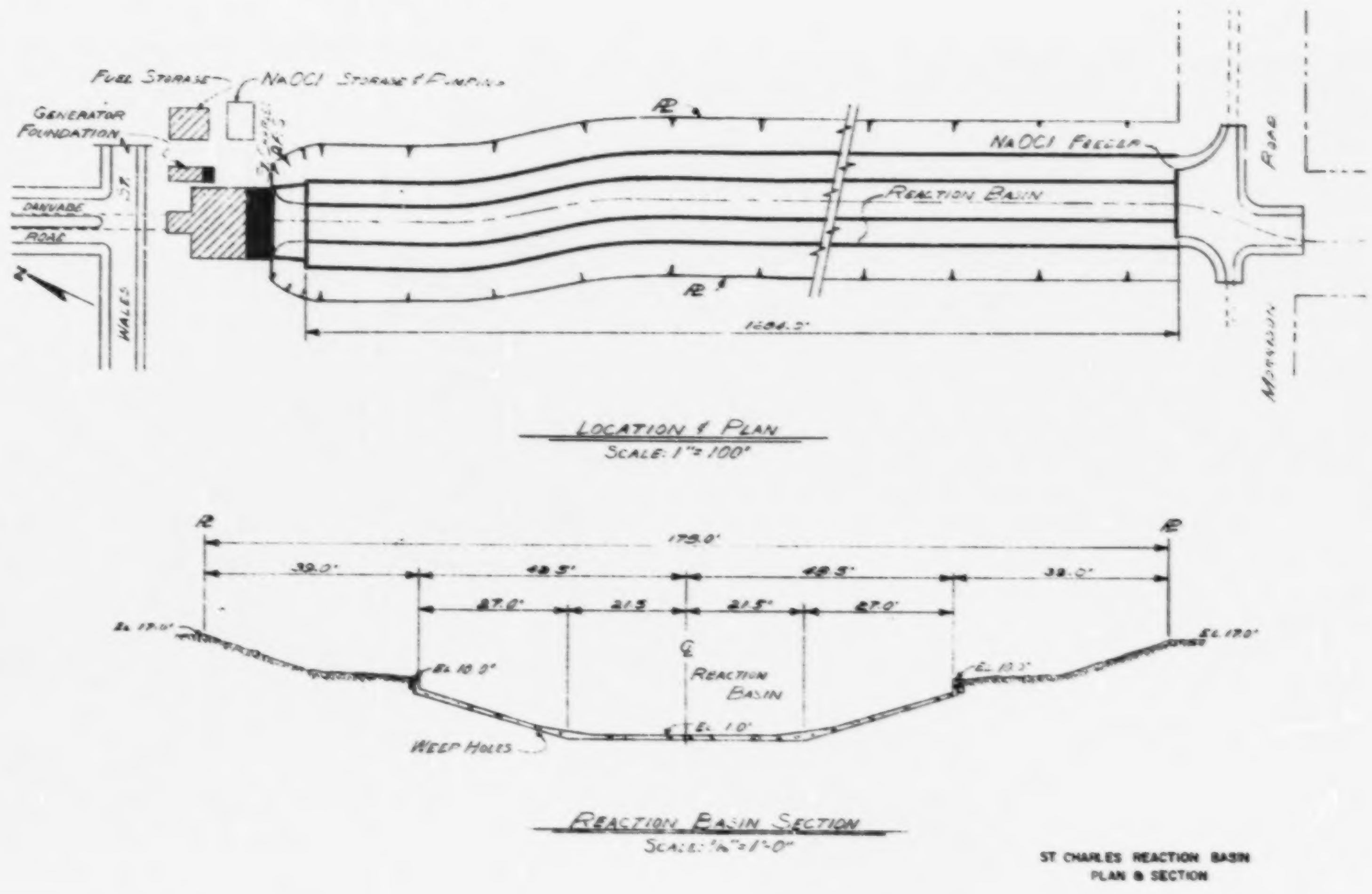
Each pumping station involved in the program utilizes a residual chlorine analyzer (total available) to indicate Cl_2R levels for the purpose of controlling NaOCl feed rate. The Cl_2R analyzers are amperometric analyzers manufactured by Wallace and Tiernan. The Cl_2R analyzers sample water from the outfall canal just downstream from the point of addition of NaOCl. The lag time to the point of sampling by the Cl_2R analyzer varies with the pumping rate at the station. Therefore, it is not feasible to attempt correlations with respect to retention time as had been hoped. Contact time varied from two to 20 minutes. The Cl_2R is displayed on a four inch strip chart recorder located on a control panel in the pumping station.

The Cl_2R analyzers specifications stipulated that they should be capable of continuous operation during the treatment periods, which could last for days or weeks. However, operation in this manner caused rapid failure of the Cl_2R analyzers and a continuous water supply from



Cl/R
Sampler St. C.-B
NaOCl Storage Tank
NaOCl Storage Tank
From Truck
P
S
Cl2 R Analyzer
Sampler St. C.-B
Bridge
T/R
St. Charles Sta.
St. Charles Canal
Control Panel
Reaction Basin
Bridge
Morrison Canal
Approx. 1684'
SODIUM HYPOCHLORITE FEEDING FACILITY
TREATMENT & SAMPLING FLOW
DIAGRAM ST. CHARLES CANAL

FIGURE 18. ST. CHARLES DPS - FLOW SHEET NaOCl FEEDING FACILITIES



Fuel Storage
NaOCl Storage & Pumping
Generator Foundation
Danvabe Road
Wales St.
N
NaOCl Feeder
Reaction Basin
℄
℄
1684.5'
Morrison Road
Location & Plan
Scale: 1" = 100'
℄
℄
179.0'
39.0'
48.5'
48.5'
39.0'
27.0'
21.5
21.5'
27.0'
El. 17.0'
El. 10.0'
℄
Reaction Basin
El. 1.0'
El. 10.0'
El. 17.0'
Weep Holes
Reaction Basin Section
Scale: 1/16" = 1'-0"
ST CHARLES REACTION BASIN
PLAN & SECTION

FIGURE 19. CROSS SECTION OF ST. CHARLES REACTION BASIN

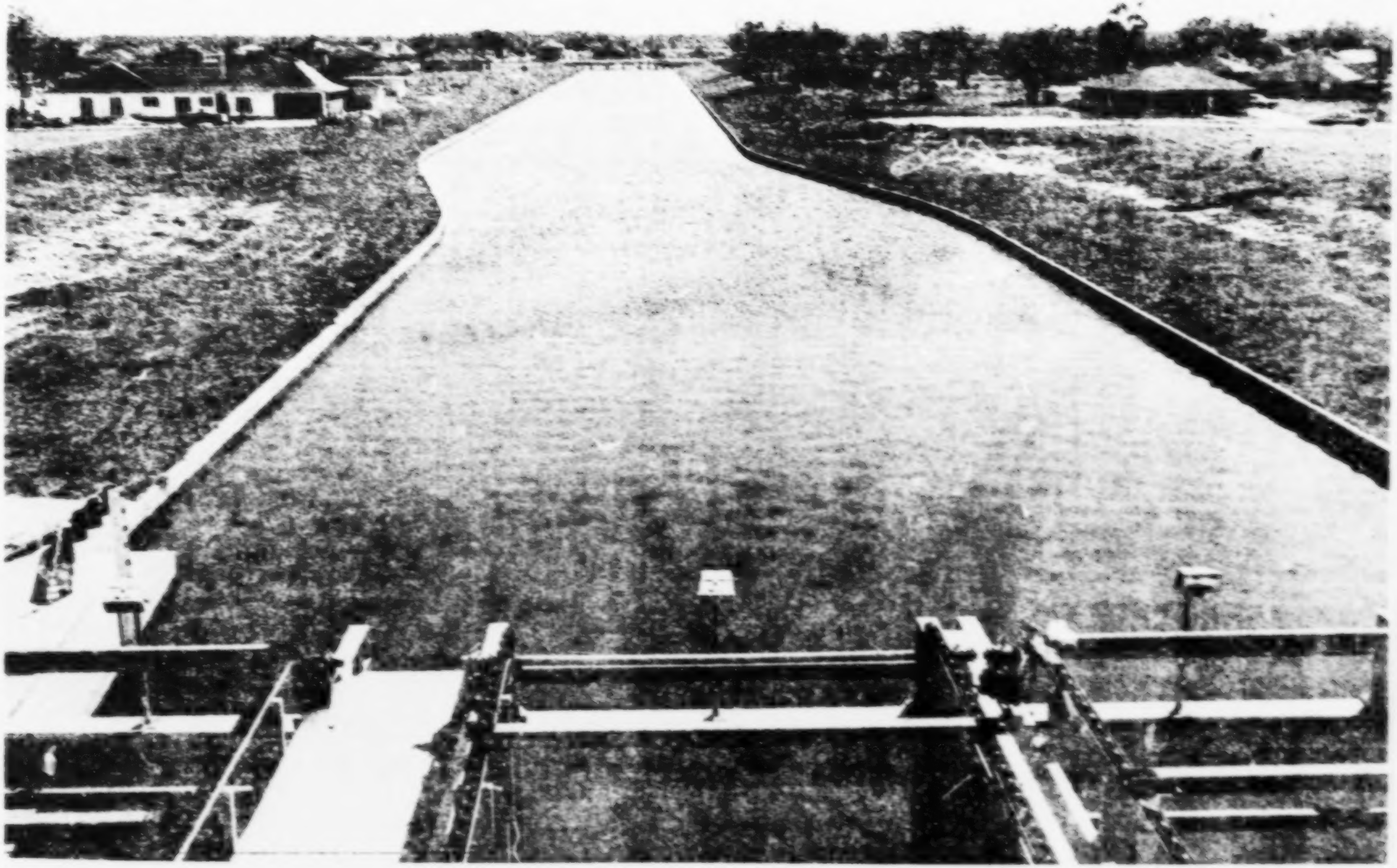


FIGURE 20. ST. CHARLES DPS - REACTION BASIN

the main distribution system of the city to keep the cells moist had to be provided at all times. This required the use of inordinate amounts of reagent and buffer solutions. It has been found that the solutions could be produced less expensively by buying the basic ingredients in bulk and producing the solutions on site. There also was plugging of the buffer and potassium iodine pump and filters had to be installed on the wastewater influent lines. On several occasions, the feed lines for the buffer and potassium iodine have split. There has also been corrosion on the solenoid activated valve which controls the city water supply and leaking of the gasket on the constant head device which measures cell flow. However, when the Cl_2R analyzers were operational, good results were obtained. At present, there does not seem to be any equipment in the Cl_2R analyzer field which can be used intermittently on wastewater without major modification. A picture of the Cl_2R analyzers at DPS #7 is shown in Figure 21.

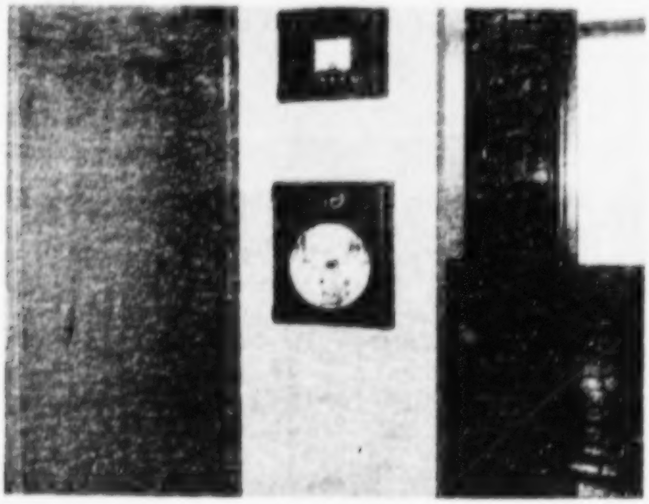


FIGURE 21. DPS #7 - RESIDUAL CHLORINE ANALYZER

NaOCl FEED CONTROL SYSTEMS

Once the Cl_2R is displayed at the control panel, the operator can vary the NaOCl feed rate to regulate the dosage level through the NaOCl feed control system. A NaOCl feed control facility consists of two pumps discharging NaOCl through a common header, an electrically positioned control valve and a magnetic flowmeter. The entire feeding facility is operated from the control panel in the pumping station. The control panel at St. Charles is shown in Figure 22. Each control panel is equipped with three strip chart recorders, a valve positioner and switches for the pumps. The recorders are four inch, electrically operated, strip chart recorders manufactured by Fisher and Porter which continuously indicate storm water temperature, rate of NaOCl feed and Cl_2R. The control valves are teflon lined butterfly valves equipped with Ramcon electric valve actuators. The actuator is positioned by a signal set by the operator at the control panel. The rate of disinfectant feed is adjusted manually by the operator who attempts to maintain a pre-determined Cl_2R level in the treated water in the discharge bay of the station during the period of pumping.

Flow of NaOCl is measured by a magnetic flowmeter. The temperature sensing system consists of a temperature bulb, capiliary tube, and signal transmitter. The Cl_2R analyzer is equipped with a signal converter and transmitter. The output of each sensing instrument is converted to a 10 to 50 ma signal, transmitted to the control panel and recorded on four inch strip chart recorders.

Little difficulty has been encountered with the piping at the storage sites. One small pipe failure at St. Charles was replaced by the manufacturer free of charge. The polypropylene lined NaOCl pumps have been a continuing source of difficulty. Due to the intermittent nature of disinfection, NaOCl is allowed to remain in the pumps for a protracted period of time. Thus, the problems encountered with the NaOCl pumps at the feeding facilities are exactly the same as those at the NaOCl manufacturing plant.

Little difficulty has been encountered with the Fisher & Porter temperature units or Beckman DO probes. The Fisher and Porter four inch strip chart recorders on the control panels at DPS #3, #4, and St. Charles were a considerable source of difficulty until surge resistors were installed.

EVALUATION PHASE SAMPLING FACILITIES

After the NaOCl had been fed to the storm water on a demand basis, a means for evaluating the efficacy of the disinfectant in reducing bacterial levels in the water had to be

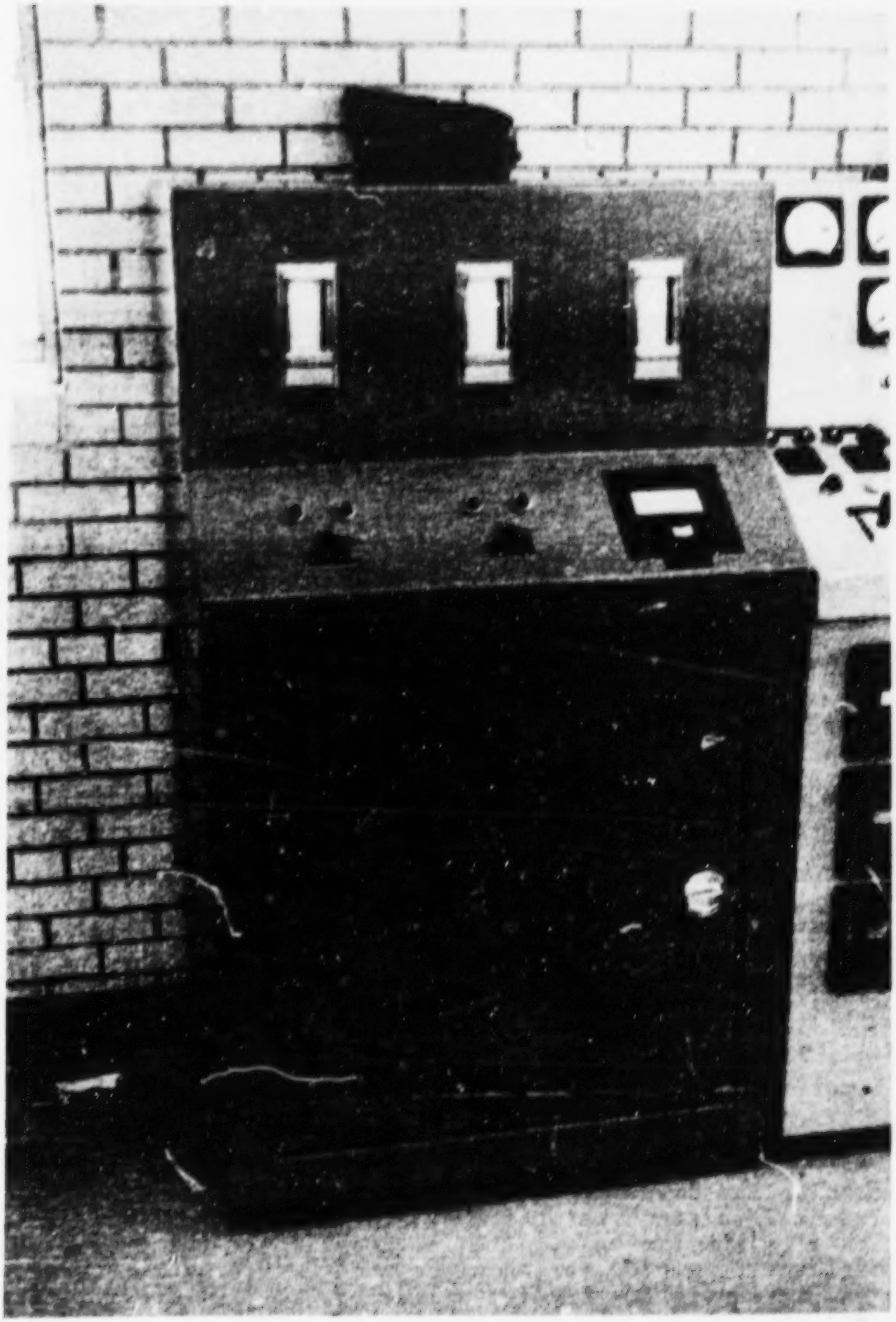


FIGURE 22. ST. CHARLES DPS - NaOCl CONTROL PANEL

provided. It was not economically feasible to keep personnel continuously on duty to take samples, and recourse was made to automatic sampling techniques. Initially, automatic analyzers were investigated. However, since the primary purpose of the program was to investigate the effect of the disinfectant on coliform bacteria levels, laboratory work was required and a holding sampler was essential to the project. The requirements of sampling were to take a pre-determined number of discrete samples, at fixed intervals, and keep them refrigerated until they could be analyzed. The water samplers had to have the capacity to take a representative sample of the storm water in the canals, both before and after treatment with disinfectant. They would also need to operate without attention during a storm. Many commercial automatic samplers were investigated, but none could meet the requirements of the project. The sampler designed and built for this project is shown in Figure 23. The samplers have the capacity to take 38 discrete samples and keep them refrigerated.

The sampler is activated by the station operator when storm water is being treated with disinfectant. Once activated, the sampler operates by opening and closing solenoid valves at pre-determined intervals. On each opening, one sample bottle is filled. Storm water is taken from the canal by a positive displacement pump. The sampler pump operates continuously during the sampling period. Thus, the water being discharged into the sample bottle is representative of the canal water and does not represent a mixture of dead water which has been stored in the influent line, and fresh water from the canal. The sample bottles are filled to overflow with excess water going to waste. The sampler pump and all parts were selected so that they would be capable of passing the 0.25 inch solids which may be present in the storm water although sampler inlet lines were provided with screens to remove such particles.

The first automatic sampler was constructed and placed in operation at DPS #3 in 1968. The prototype sampler used copper tubing and fittings for all internal parts and bronze solenoid valves. After several weeks of operation, corrosion was noticed on the valve seats and the copper tubing had discolored. After this experience, it was decided to construct the automatic samplers utilizing PVC or aluminum fittings. Thus, a redesign of the prototype automatic sampler was required and the second and subsequent samplers were constructed utilizing PVC pipe and fittings. The configuration of the sampler remained basically the

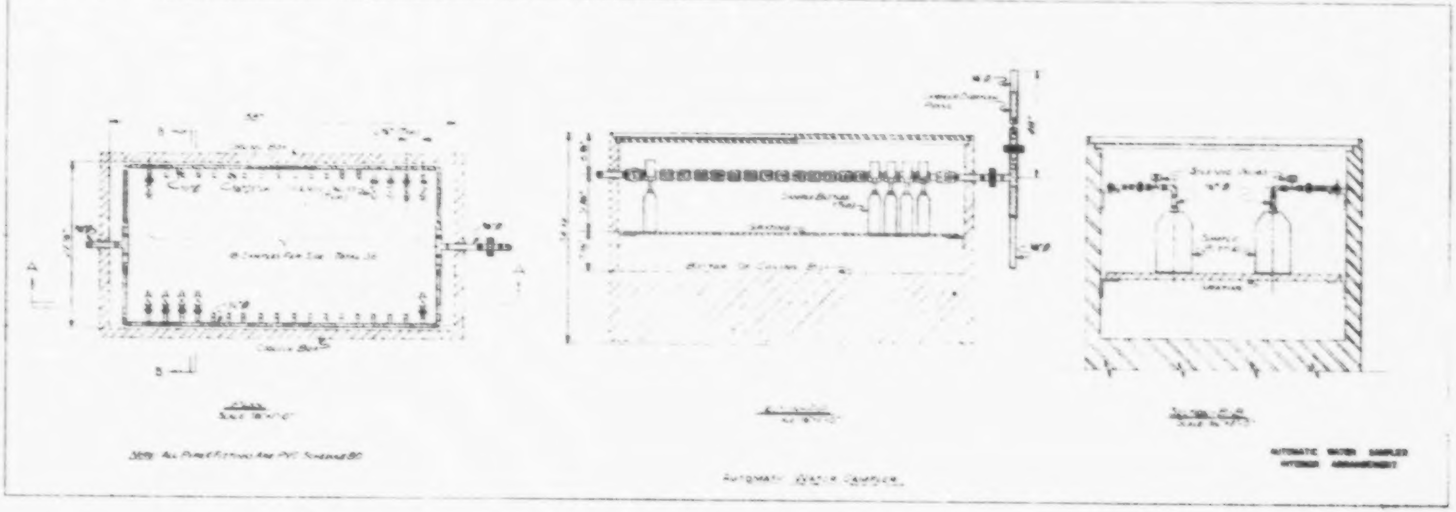


FIGURE 23. AUTOMATIC WATER SAMPLER - INTERIOR VIEW

same.

The automatic samplers are located in the pumping stations at DPS #3, and #4 and in portable metal buildings at DPS #7 and St. Charles Station. The metal buildings are the knock down type, bolted construction and are skid mounted to allow the location of sampling facilities to be moved (Fig. 24). This feature became very useful during the post-construction evaluation when the downstream samplers had to be moved from DPS #3 and #4 to DPS #7.

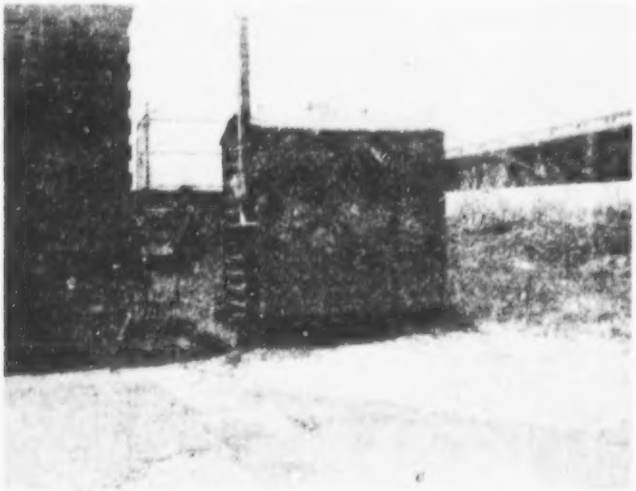


FIGURE 24. EXTERIOR VIEW OF METAL SAMPLER BUILDING

The samplers have worked as designed. There has been some difficulty in keeping prime with the sampler pumps, but this has been traced to air leaks or siphons in the suction lines. The main difficulty at the sampling sites is vandalism. The control wires from the pumping stations to the sampler sheds, and the suction lines from the outfall canals to the sampler sheds have been repeatedly cut and damaged. The sample pump and electric controller from the pre-treatment locations at St. Charles were stolen and had to be replaced. Several bullet holes have also been found in the sampler buildings at the St. Charles Station.

SECTION IX

EVALUATION PROGRAM

GENERAL

To demonstrate the feasibility of reducing the coliform density in polluted storm water pumpage by hypochlorination, three distinct water sampling and evaluation programs were formulated. The three programs were:

1. A five year base period evaluation which analyzed data available from a five year period before the program began.
2. A pre-construction evaluation program, lasting 22 months, during which the outfall canals were sampled and analyzed for bacterial and chemical pollution prior to the use of NaOCl.
3. A post-construction evaluation program which analyzed the effects of disinfection on the storm water and the outfall canals.

The five year base period data extended from July 1, 1961 to June 30, 1966. An analysis of this data provided the preliminary design criteria for the NaOCl manufacturing and feeding facilities and gave an indication of the magnitude of the bacterial pollution. The Pre-Construction Evaluation Program, essentially a sanitary analysis, was begun March 1, 1967 and continued through December 30, 1968.

Chemical, physical and bacterial tests were run and the data analyzed to determine the nature and magnitude of the pollution present in the storm water, and to establish base line parameter levels for the outfall canals. Upon completion of the disinfectant feeding facilities, a post-construction evaluation program was carried out. This program demonstrated the feasibility of reducing, by several orders of magnitude, the indicator coliform density in bacterially polluted storm water using large outfall canals in populated areas as disinfection facilities.

FIVE YEAR BASE PERIOD EVALUATION

GENERAL

The Five Year Base Period Evaluation was carried out utilizing data which had been gathered by the Sewerage and Water Board of New Orleans, New Orleans Board of Health, and the Louisiana State Board of Health from July 1, 1961 to June 30, 1966. This data was used to:

1. Estimate the level of bacterial pollution in the drainage canals.
2. To determine the quantity and frequency of storm water pumpage.
3. Estimate the amount of NaOCl which would be required to disinfect the water.

Sampling

Data records consisted of water samples taken from three outfall canals; Orleans, London, and Citrus, and from Lake Pontchartrain. The samples from the canals were analyzed for total and fecal coliform densities. Bacterial densities were derived by the Sewerage and Water Board using the membrane filter technique, while both multiple tube and membrane filter techniques were used by the New Orleans, and Louisiana Boards of Health on Lake Pontchartrain samples. Bacterial densities that were valid for more than one dilution for the membrane filter technique were averaged on the basis of total volume sampled. Storm water quantity and pumping rate data were obtained from the log books of the pumping stations. Quantity was determined by multiplying the capacity rating of the pump by the time the pump held suction. Rainfall data were taken from the rain gauges at the pumping stations.

Five Year Base Period Results

Data gathered during the five year sampling program were plotted for visual inspection. The bacterial and physical parameters from DPS #7 are shown in Figure 25. No visual correlations were evident. To further analyze the data, coliform, water pumped, and rainfall values were punched on

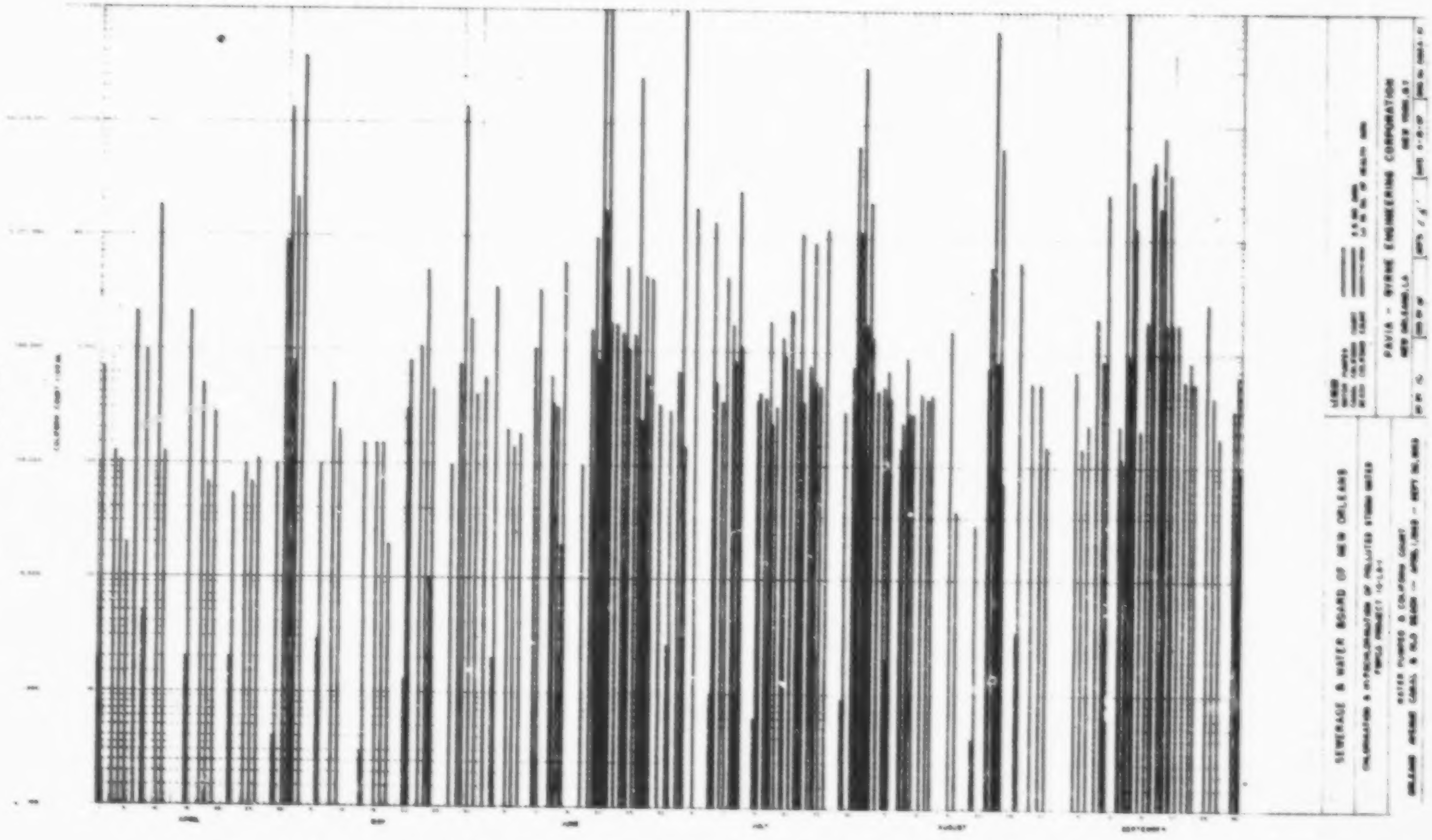


FIGURE 25. DPS #7 BACTERIAL & PHYSICAL PARAMETERS 5 YEAR BASE EVALUATION PROGRAM

computer cards. Computer programs were developed to generate intensity-frequency data for the anticipated use of NaOCl at the drainage pumping stations. Design data for the planned St. Charles station were developed from information available from the Citrus station, which drains the same area. Intensity-frequency data for water pumped on a one day and a five day basis were developed. These data provided the basis for estimating the quantities of NaOCl required during the project.

The rainfall pattern is essentially the same for each station. However, since each station has a different pumping capacity and serves a different drainage area there are slight differences in the water pumped data. The Orleans Avenue and the London Avenue canal serve combined residential and industrial areas with high runoff coefficients. The St. Charles station serves a relatively undeveloped rural area with a low runoff coefficient. The factor of different drainage areas is also brought out in the total and fecal coliform levels in the Orleans, London, and Citrus canals (Table 5). The total coliform level in the Citrus canal is relatively high, while the fecal coliform level is approximately the same as the London canal. The Orleans Avenue canal was higher in both types of bacteria.

The high total coliform level in the Citrus canal is partly due to the almost constant pumping situation. If the canal is allowed to remain fallow after a pumping sequence, there is a tendency for the coliform levels to gradually drop as the nutrients in the canals are used up and/or settle to the bottom. The low fecal coliform levels in the Citrus canal were probably due to the undeveloped nature of the area and the attendant low runoff coefficient. Since there were few human residents most fecal coliform pollution must have come from the warm-blooded animal population (2). This population includes domesticated animals as well as an abundance of wildlife. In fact, this area was often frequented by hunters.

It should be noted that the Citrus station which served the eastern portion of the city was replaced by the St. Charles station in 1967. Thus, the data for the Five Year Base Period are from the Citrus canal, while the Pre and Post-Construction Evaluation data are from the St. Charles reaction basin. It was felt that no substantial errors would be introduced in the drainage water characteristics by this change and the data from the two different stations are considered to be characteristic of this drainage area.

The London Avenue canal has the lowest pumping frequency and coliform level. This is due to the fact that within limitations

TABLE 5

BACTERIAL PERCENTILE LEVELS: 5 YR. BASE PERIOD

	Total Coliform			Fecal Coliform		
	25%	50%	75%	25%	50%	75%
London Avenue Canal (DPS #3, 4)	2,000	10,000	65,000	300	1,000	5,000
Orleans Ave. Canal (DPS #7)	4,000	18,000	130,000	400	1,000	7,000
Citrus Canal (Citrus)	1,000	5,000	110,000	400	2,000	5,200

governed by the capacity of the drainage system and the location and intensity of the rainfall, DPS #3 pumps into the Florida Avenue canal. Water from the Florida Avenue canal is then repumped to Bayou Bienvenue or under extremely light loading to the Mississippi River. Thus, the heavy bacterial and chemical loading of the outfall canal during the initial "flushing" of the system does not enter the London Avenue canal. Since there are many routes drainage water can take, a schematic of the possible flows to and from the pumping station in the project is shown in Figure 27.

The Orleans canal, which has the highest bacterial levels, receives all storm water reaching DPS #7. However, this data is influenced by the location of the sampling point which is closer to the pumping station than on the London Avenue canal. Thus storm water, with its high bacterial densities, reaches the sampling point even at low pumpage rates and before die off can occur. Also, the higher salinity levels in the lake don't exert the same influence here. However, all the canals were highly polluted bacteriologically as 90% of all total coliform readings were above the limit of 1,000/100 ml recommended for body contact recreation waters by the Louisiana State Board of Health.

Lake Pontchartrain data supplied by the Louisiana State Board of Health indicated that the lake is more polluted after pumping periods. However, the lack of a systematic testing program to eliminate other sources of pollution preclude assigning the increased bacterial levels entirely to storm water pumpage.

The intensity-frequency data developed for rainfall and water pumped at DPS #7 (Table 6) demonstrate the quantities of water involved. From the data, it is evident that some rainfall can be expected on approximately one day out of every three, and that one inch or greater rainfall can be expected approximately fifteen days per year. However, even though most pumping stations are equipped with an automatic rain gauge, the operating characteristics of the drainage system prevent obtaining any valid correlation between quantity of rainfall and quantity of water pumped into the outfall canals. In developing intensity-frequency data for water pumped at DPS #3, and #4, only that water pumped into the London Avenue canal was considered.

The data indicated that water was pumped on approximately 20% of the days which is somewhat less than the rainfall frequency since not every rainfall results in pumpage. Also, when pumpage occurred, it exceeded 20,000,000cfd on 30% of the days. When data from hurricane periods and other

TABLE 6

RAINFALL & WATER PUMPED FREQUENCIES

% of Days

	RAINFALL		RAINFALL >1.0 in.	
	Base Period	Pre-Const	Base Period	Pre-Const
DPS 7	27.0	27.0	5.0	4.0
DPS 3	27.5	32.0	5.0	3.5
DPS 4	30.0	29.0	5.0	4.0
Citrus DPS	31.5	29.0	6.5	3.5

	WATER PUMPED		WATER PUMPED $>5x10^6$cfd		WATER PUMPED $>10x10^6$cfd	
	Base Period	Pre-Const	Base Period	Pre-Const	Base Period	Pre-Const
DPS 7	45.0	39.0	6.0	11.0	4.0	6.5
DPS 3	14.0	53.0	7.5	8.5	3.5	4.5
DPS 4	14.5	9.5	3.5	2.5	2.0	1.5
Citrus DPS	87.5	69.5	22.5	12.5	11.5	5.0

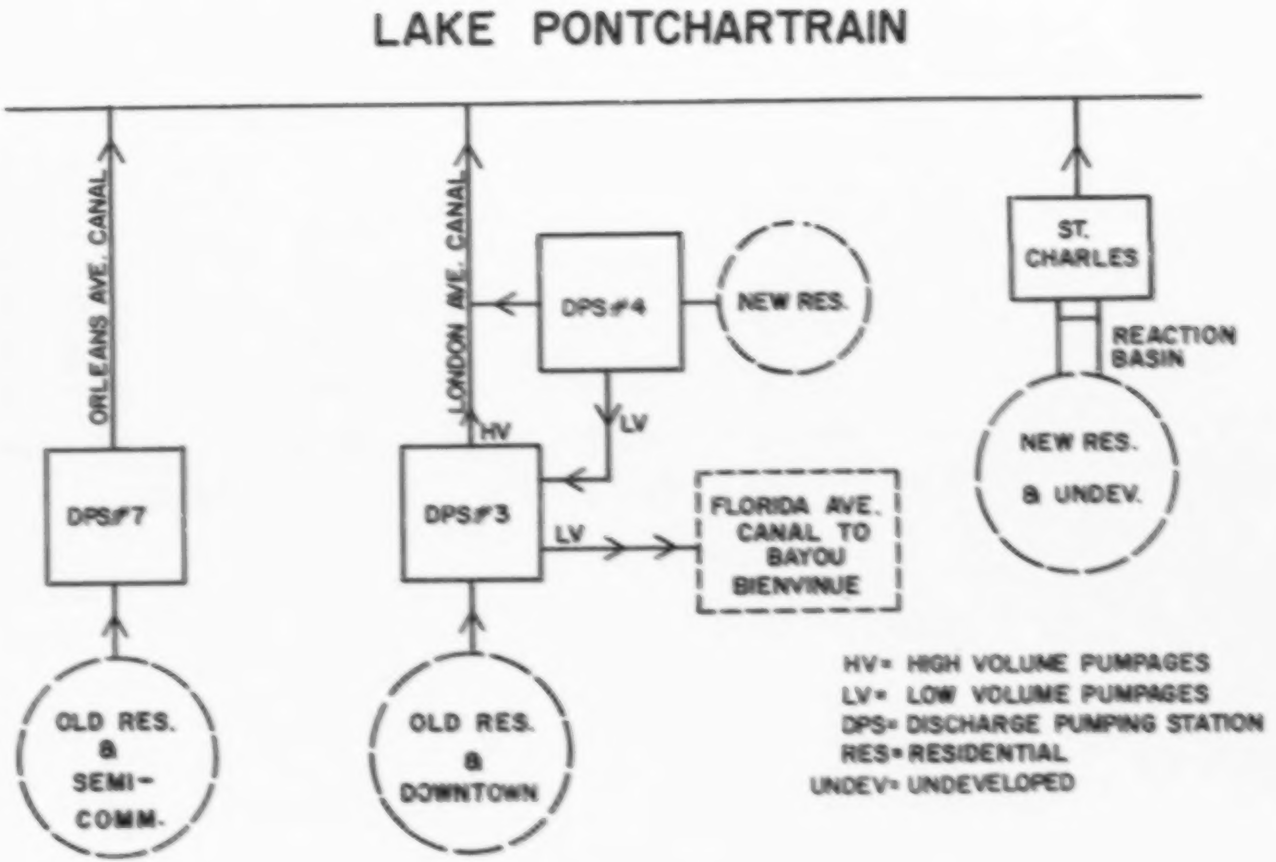

LAKE PONTCHARTRAIN
ORLEANS AVE. CANAL
LONDON AVE. CANAL
HV
LV
LV
DPS#7
DPS#3
DPS#4
NEW RES.
ST. CHARLES
REACTION BASIN
NEW RES. & UNDEV.
FLORIDA AVE. CANAL TO BAYOU BIENVINUE
OLD RES. & SEMI-COMM.
OLD RES. & DOWNTOWN
HV= HIGH VOLUME PUMPAGES
LV= LOW VOLUME PUMPAGES
DPS= DISCHARGE PUMPING STATION
RES= RESIDENTIAL
UNDEV= UNDEVELOPED

FIGURE 26. SCHEMATIC DIAGRAM OF DRAINAGE SYSTEM INVOLVED IN PROJECT

extraordinary rainfalls were removed from consideration, it was found that treatment facilities for average water pumpages of 79,277,000 cfd or 529,990,000 gpd would be needed for three pumping stations originally scheduled to use NaOCl, and 27,600,000 cfd or 204,240,000 gpd at DPS #7, originally scheduled to use Cl_2. The total quantity of storm water requiring treatment was 106,877,000 cfd or 734,230,000 gpd. DPS #7 was subsequently converted to NaOCl in the interest of safety.

Five day periods were considered in planning disinfectant and transportation requirements. The data indicated that NaOCl treatment facilities would be required for 277,258,000 cf (2,193,890,000 gal.) of storm water in five days which was slightly more than five average day pumpages.

PRE-CONSTRUCTION EVALUATION PROGRAM

General

The 22 month Pre-Construction Evaluation Program which followed the Five Year Base Period Evaluation was basically a sanitary water analysis program. The objectives of this program were:

1. To establish a baseline of total and fecal coliform levels in storm water discharged to the outfall canals.
2. To determine the overall quality of the storm water discharged and the quality of the water in the outfall canals between pumping periods.
3. To determine an empirical relationship between coliform levels and one or more easily determinable parameters.

Sampling Program

The Pre-Construction Evaluation Program consisted of recording rainfall data from gauges at the pumping stations, water pumpage data from the pumping station log books, and taking grab samples from the pumping station suction bays and outfall canals for bacteriological and chemical analysis. The grab samples were taken every Monday, Wednesday, and Friday from pre-selected points on the Orleans, London and Citrus canals, the suction bays of DPS #4, and #7, and once a week, weather permitting, in Lake Pontchartrain. The water samples were all taken at a depth of approximately 24 in. The sampling locations in the canals were approximately the same for the pre-construction program as for the five year base period to provide continuity. The sampling points are shown in Figure 27.

The grab samples from the stations and outfall canals were analyzed for the following parameters:

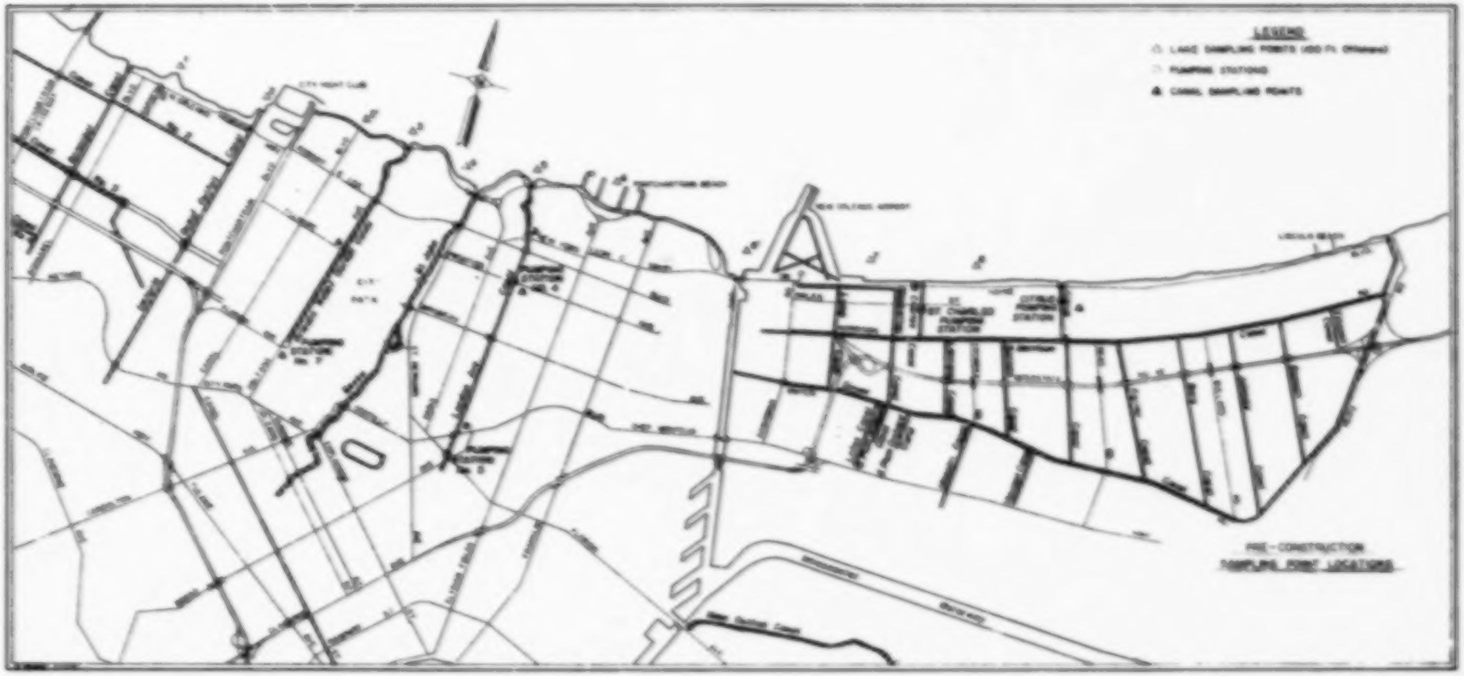
Total coliform
Fecal coliform
Enterococci
COD
DO
BOD
Suspended solids
pH
Chlorine demand
Temperature

All samples were analyzed in accordance with the procedures found in Standard Methods for the Examination of Water and Wastewater, 12th Edition.

As in the Five Year Base Period Evaluation, extensive data were collected. The weekly sampling and pumping data combined to give over 25,000 items of data. In order to manipulate such a mass of data, a computer again had to be utilized. The computer facilities used during the Five Year Base Period Evaluation were not available during the pre-construction program and a time-sharing computer facility was utilized.

The initial step taken in the analysis was to compile, tabulate and plot the data. The data was plotted by sampling location and representative curves for coliform and physical parameters at DPS #7 are shown in Figure 28. Three curves were required for each sampling location to provide sufficient resolution of the parameters. Water pumped was plotted on each of the curves because it is the parameter which indicates the existence of a new set of initial conditions.

The data curves indicate the overall quality and quantity of the water to be treated. The parameters were statistically analyzed to provide quantitative measures of the water quality. Also, an effort was made to obtain a correlation between one or more of the parameters susceptible to continuous monitoring and the total coliform density. Thus, a method which would give a quick indication of the coliform level would be available. Four parameters were chosen for extensive study; total coliform, suspended solids, temperature, and dissolved oxygen. Total coliform was chosen because the reduction of this parameter was the prime concern of this project. The other three



LEGEND
LAKE SAMPLING POINTS (100 Ft. Offshore)
PUMPING STATIONS
CANAL SAMPLING POINTS
NEW ORLEANS AIRPORT
ST. CHARLES PUMPING STATION
LINCOLN BEACH
CITY YACHT CLUB
CITY PARK
PRE-CONSTRUCTION
SAMPLING POINT LOCATIONS

FIGURE 27. PRE-CONSTRUCTION EVALUATION PROJECT SAMPLING POINTS

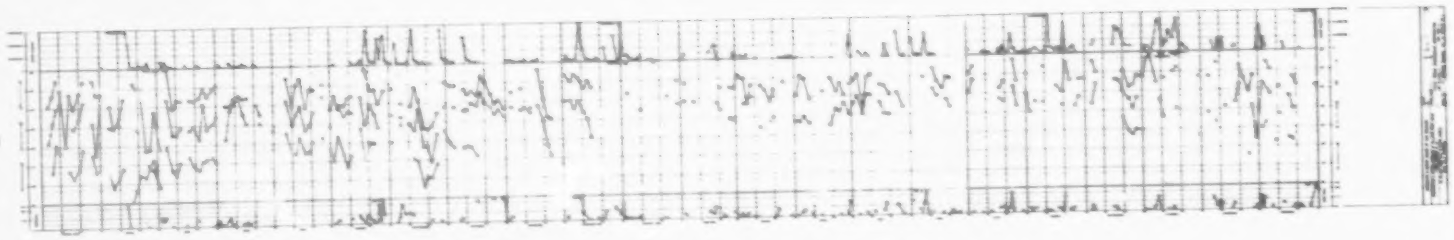


FIGURE 28. DPS #7 - PRE-CONSTRUCTION EVALUATION PROGRAM -
BACTERIAL, RAINFALL & WATER PUMPED DATA

parameters were chosen because they could all be quickly measured and continuously monitored by automatic analyzers. If a correlation was found, the incoming bacterial density could then be calculated using the correlation equation. The bacterial density desired in the effluent would then be used to calculate the degree of reduction required. Once the degree of reduction was known, the dosage of NaOCl above that required to satisfy the chlorine demand would be known.

The values for these parameters were placed on punch cards and statistical tests were performed. Typical frequency histograms for the four parameters were all skewed to the right as can be seen in Figures 29 through 32. Dissolved oxygen, suspended solids, and temperature distributions were fairly continuous but did not appear to have a gaussian distribution. The total coliform data tended to be very discrete and no conclusion could be made as to the distribution. When total coliform readings were grouped to include only values on days water was pumped, they were found to be normally distributed. However, this was revealed to be more a function of the sampling procedure than a property of the data. The samples that were recorded on pumping days could have been taken before, during, or after a pumping period. Since the coliform levels depend on the time the sample was taken, it is not surprising that the data were normally distributed. No log transformation or chi square tests were performed, but when the data were plotted on a log basis, it did plot normally. Since the other parameters did not appear to display any of the standard distributions, further statistical distribution tests were abandoned.

Several curves were drawn using the four parameters as independent and dependent variables. At first, it seemed that some periodic relations existed between total coliform, dissolved oxygen, and suspended solids when temperature was held constant. Upon further analysis this was not found to be the case.

A second approach would have separated the data into various concentration levels for each parameter. Then using one parameter as the dependent variable, the levels of two other parameters are chosen as independent variables and used in composing factorial arrangements. These factorial arrangements could then be subjected to an analysis of variance. Those main effects and interactions between constituents which tested as significant in the analysis of variance would be included in a multiple, non-linear regression analysis utilizing all the data for the significant parameters. It was felt that this procedure would provide either one or a series of equations from which the necessary quantity of

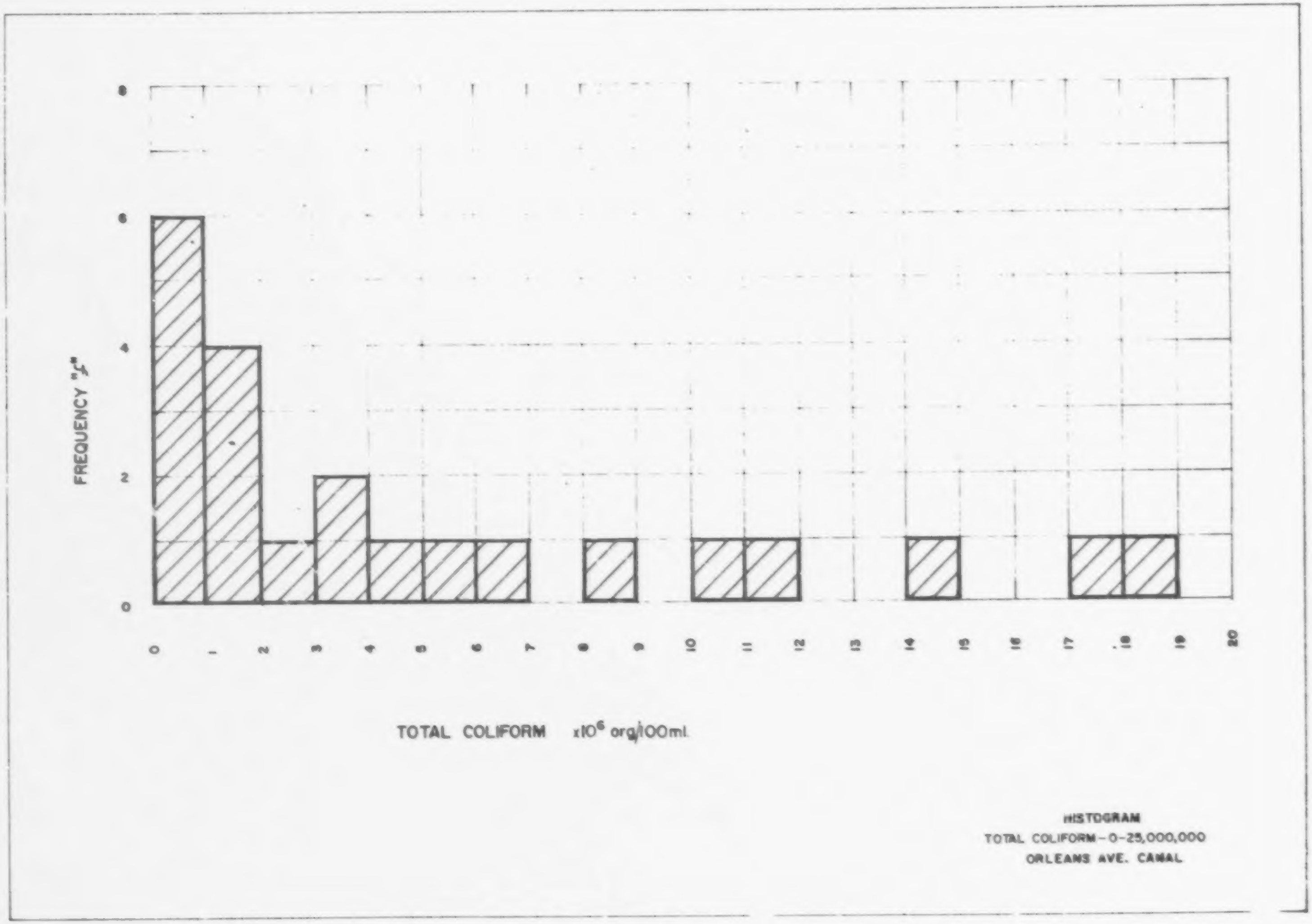


FIGURE 29. ORLEANS AVENUE CANAL (DPS #7) PRE-CONSTRUCTION EVALUATION PROGRAM - TOTAL COLIFORM HISTOGRAM

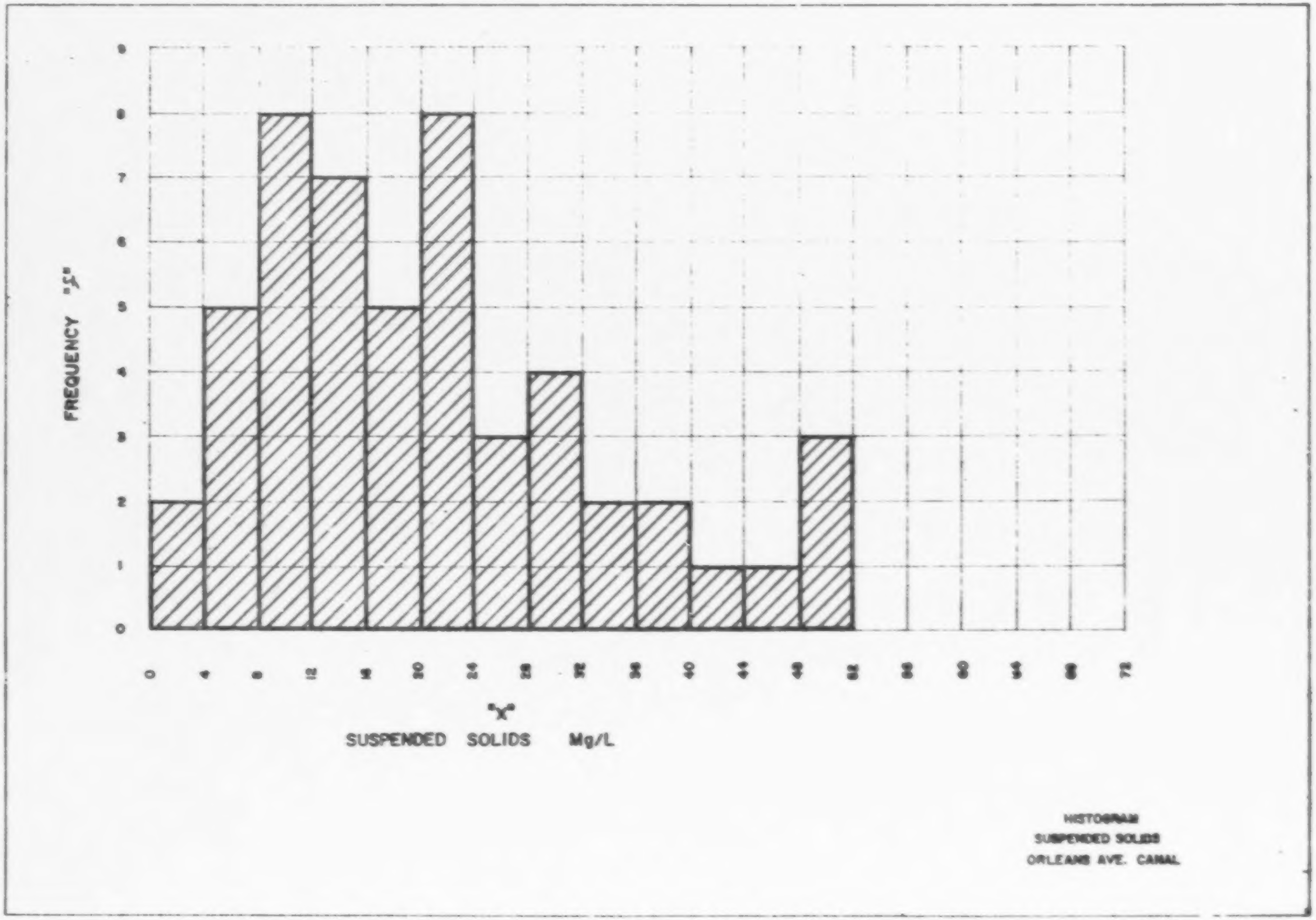


FIGURE 30. ORLEANS AVE. CANAL (DPS #7) PRE-CONSTRUCTION EVALUATION PROGRAM

SUSPENDED SOLIDS HISTOGRAM

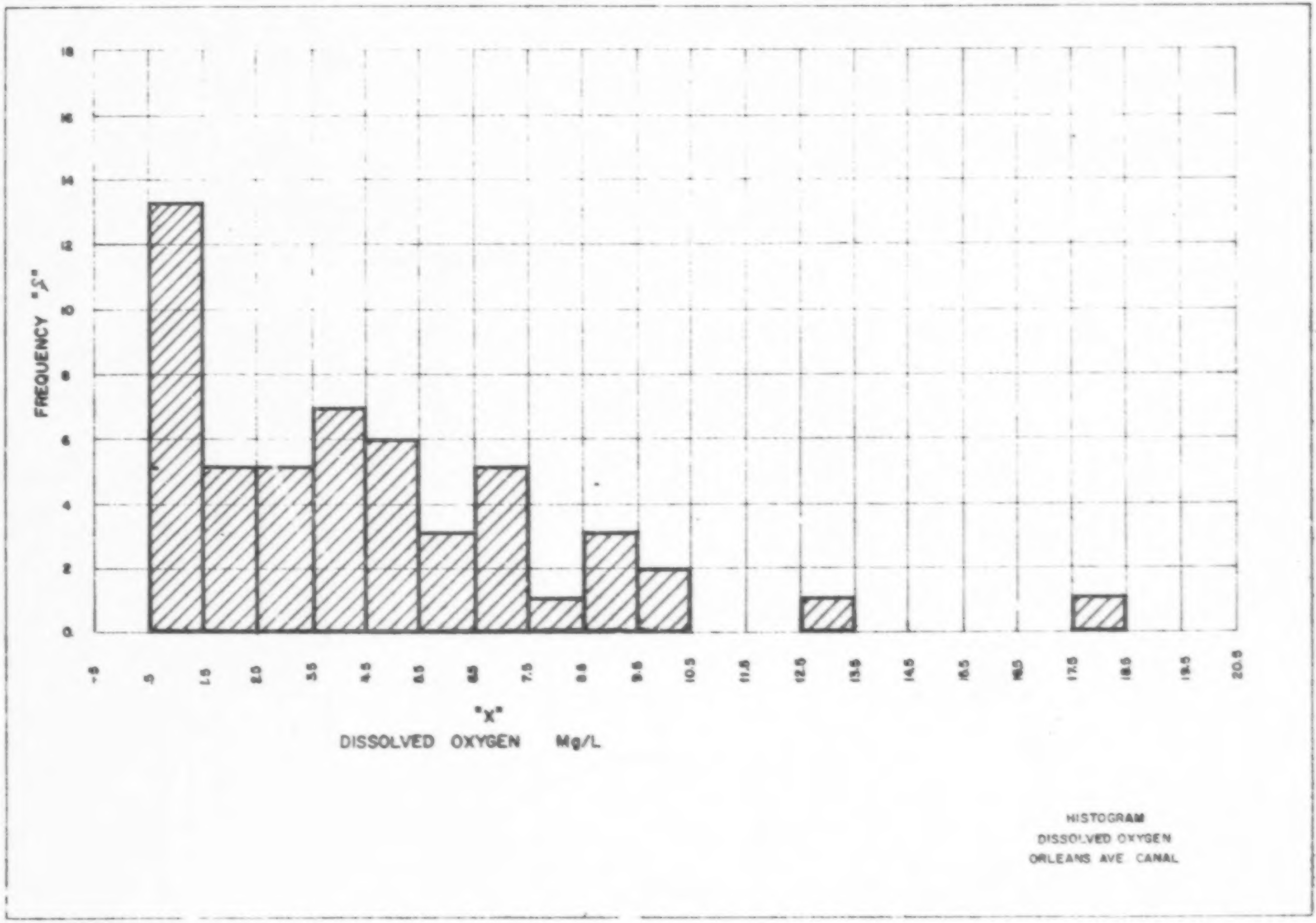


FIGURE 31. ORLEANS AVE. CANAL (DPS # 7) PRE-CONSTRUCTION EVALUATION PROGRAM

DISSOLVED OXYGEN HISTOGRAM

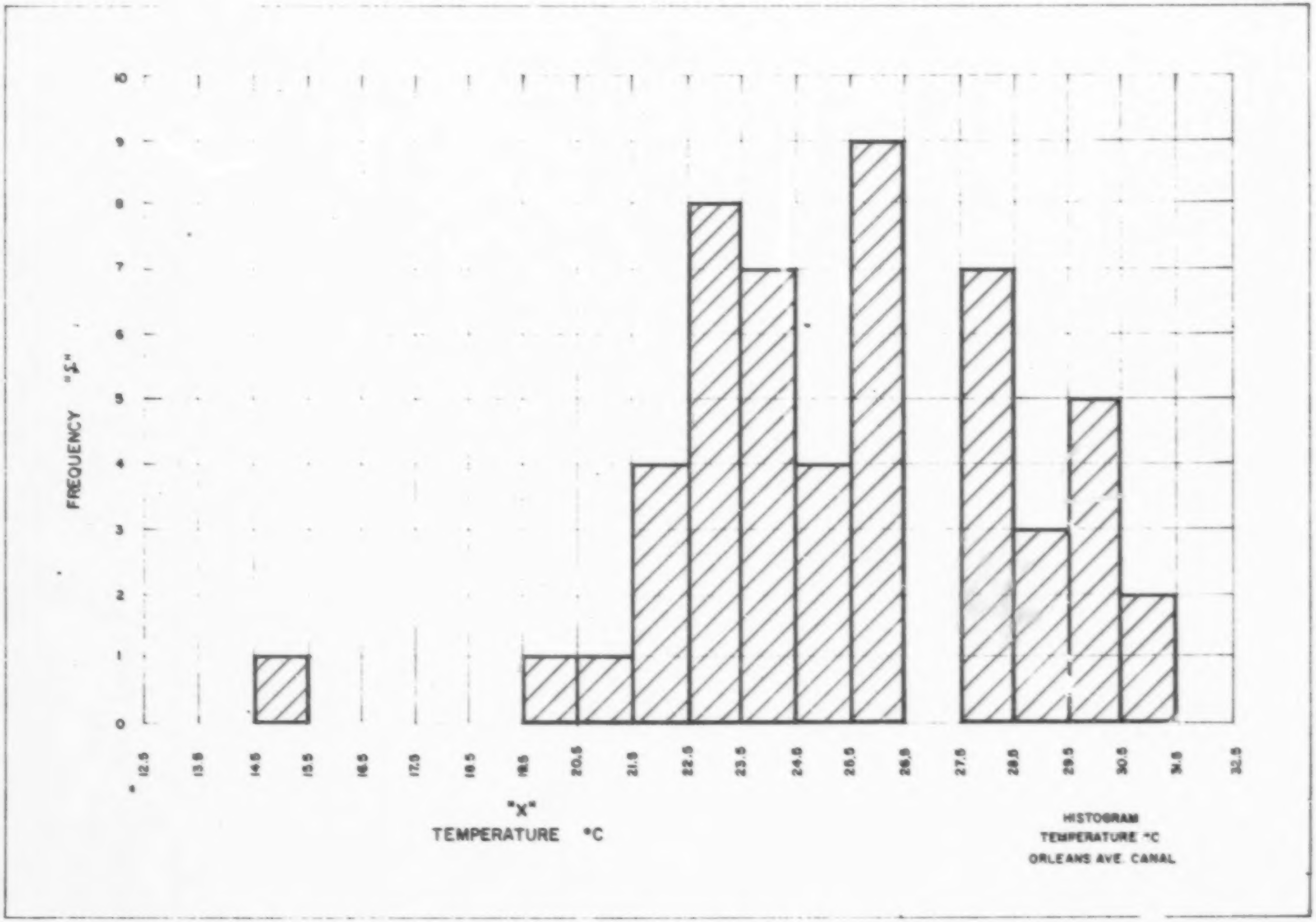


FIGURE 32. ORLEANS AVE. CANAL (DPS #7) PRE-CONSTRUCTION EVALUATION PROGRAM TEMPERATURE HISTOGRAM

NaOCl required to obtain specific residual chlorine levels on the discharge side of the pumping station could be determined.

Analysis of Variance

The general, linear, analysis of variance model (co-variance if more than one independent variable is involved) has the form (3)

$$Y = \alpha x + \beta z + \varepsilon$$

where Y is the dependent variable, x and z are independent variables, α and β are effect coefficients of the independent variables, and ε is the experimental error. Invariance of the effect coefficients of the independent variables, one of the prime assumptions of this model cannot be met when considering data taken during the Pre-Construction Evaluation Program because the drainage system has time, temperature, spatial and concentration dependencies.

Time dependency is found on several levels and contains both trends and stochastic series. First, the characteristics of the entire drainage area are changing with time. This can be seen in Table 7 where the total coliform and fecal coliform levels for the five year base period are compared with data from the Pre-Construction Evaluation Program. This increase of levels with time is self-evident. Also, the means of the various parameters vary with months as shown in Figures 33 through 36 and, thereby, display a seasonal effect. Third, the length of time between pumping periods also effects the data and, by virtue of its dependency on rainfall, is stochastic.

The effects of the diurnal cycle, temperature, space, and concentration are well documented in the literature. No attempt will be made to review this aspect of the changing character of the drainage system.

In an effort to remove several of the time and temperature effects, a program to structure the data by day after pumping was written and run. The results were then subgrouped by level as shown in Figure 37 for DPS #7. As expected, temperature and season were related. The phenomenon of total and fecal coliform die off with time was also noted. This die off arises from their exposure to the relatively harsh biological environment. BOD and COD values did show a

TABLE 7

BACTERIAL PERCENTAGE LEVELS: 5 YR BASE PERIOD vs PRE-CONSTRUCTION EVALUATION

TOTAL COLIFORM

	5 YR			PRE-CONSTRUCTION		
	25%	50%	75%	25%	50%	75%
London Ave Canal (DPS #3, 4)	2000	10,000	65,000	16,000	80,000	470,000
Orleans Ave Canal (DPS #7)	4000	18,000	130,000	105,000	1,050,000	6,000,000
Citrus - St Chas.	1000	5,000	110,000	19,000	3,000	250,000

FECAL COLIFORM

	5 YR			PRE-CONSTRUCTION		
	25%	50%	75%	25%	50%	75%
London Ave Canal (DPS #3, 4)	300	1,000	5,000	650	4,900	21,000
Orleans Ave Canal (DPS #7)	400	1,000	7,000	5,500	40,000	250,000
Citrus - St Chas.	400	2,000	5,200	900	5,000	20,000

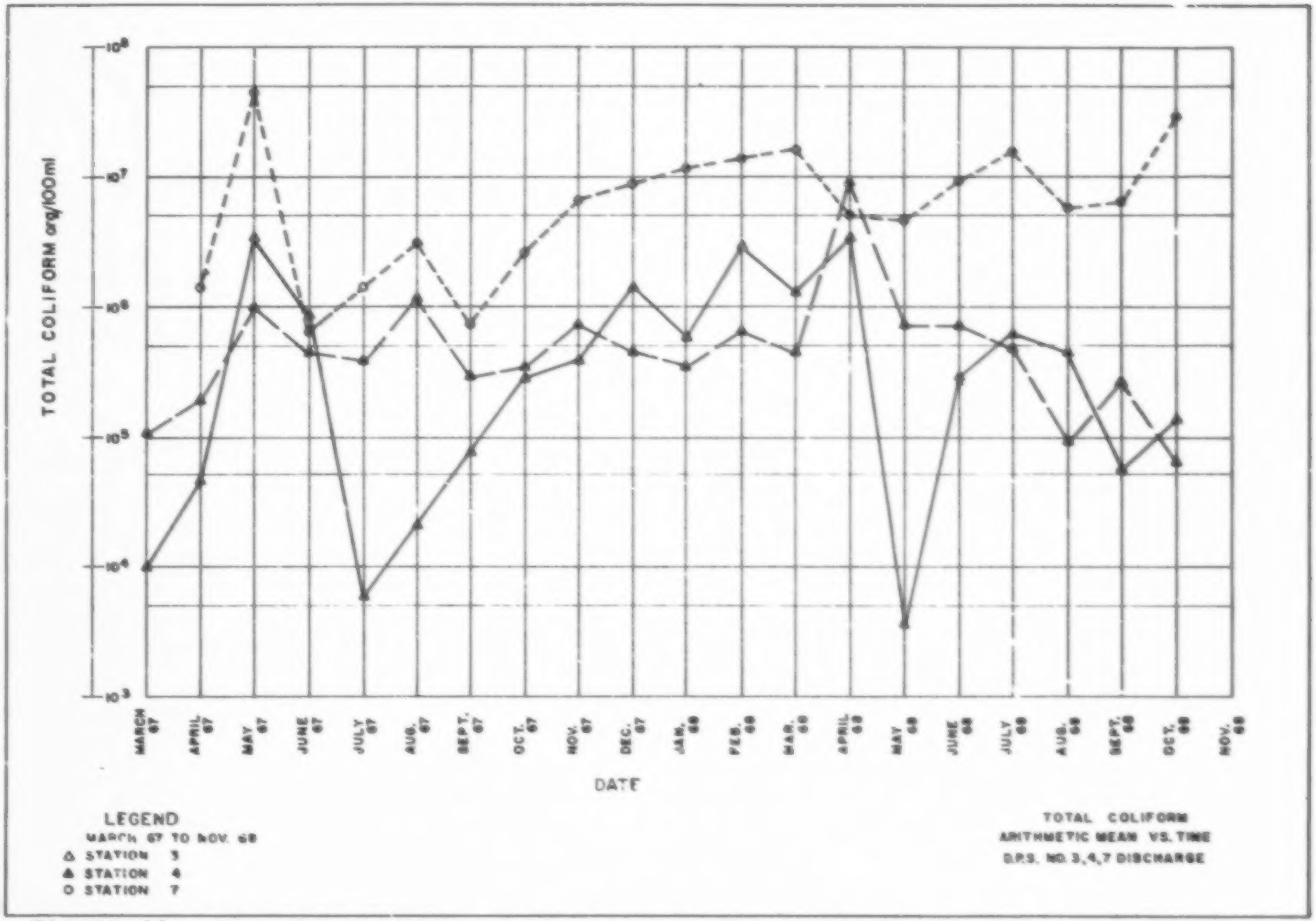


FIGURE 33. PRE-CONSTRUCTION EVALUATION PROGRAM - TOTAL COLIFORM - ARITHMETIC MEAN vs TIME DPS #3, 4, 7 DISCHARGE

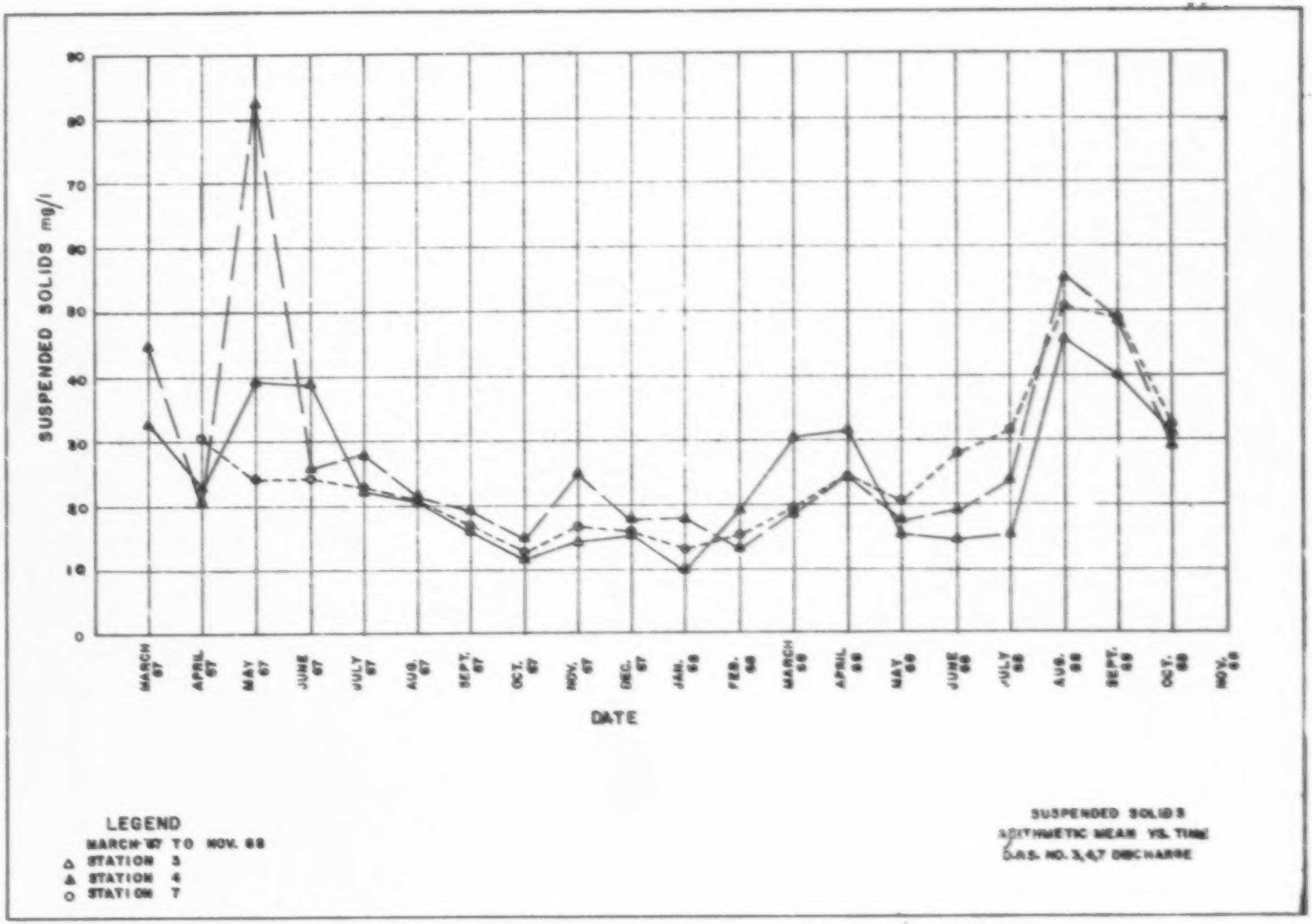


FIGURE 34. PRE-CONSTRUCTION EVALUATION PROGRAM SUSPENDED ~~SOLIDS~~

ARITHMETIC MEAN vs TIME DPS #3, 4, 7 DISCHARGE

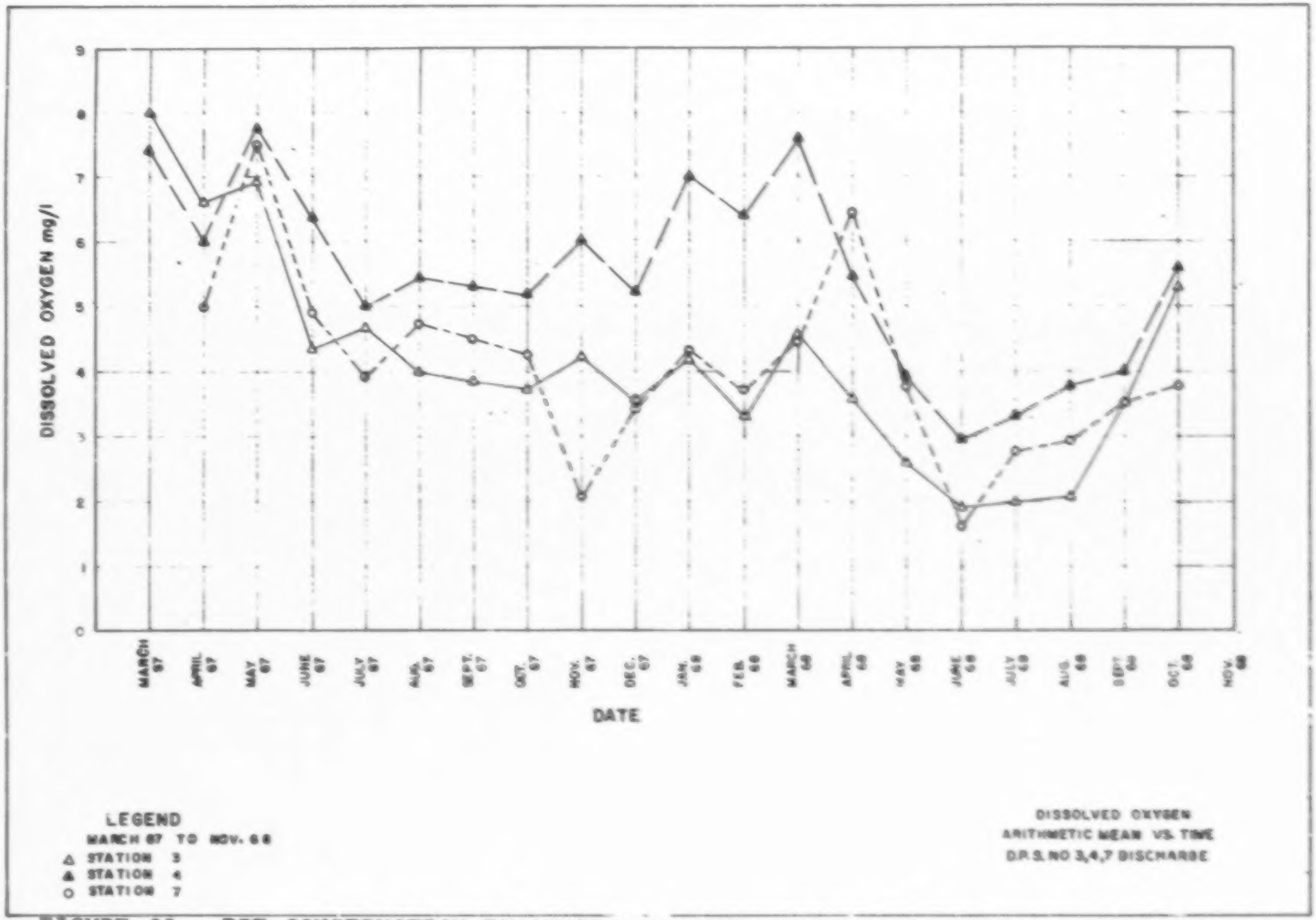


FIGURE 35. PRE-CONSTRUCTION EVALUATION PROGRAM - DISSOLVED OXYGEN - ARITHMETIC MEAN vs. TIME DPS #3, 4, 7 DISCHARGE

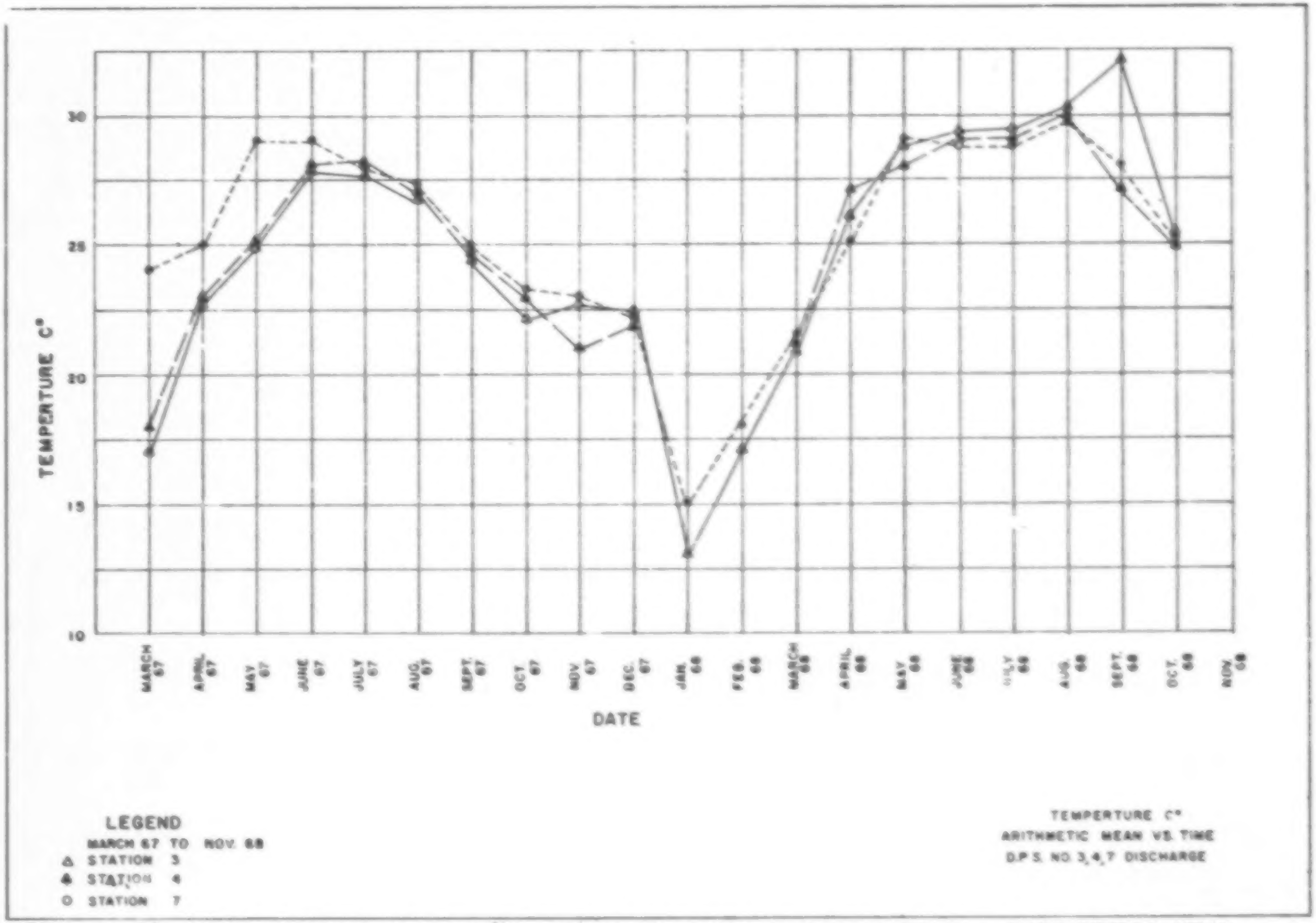
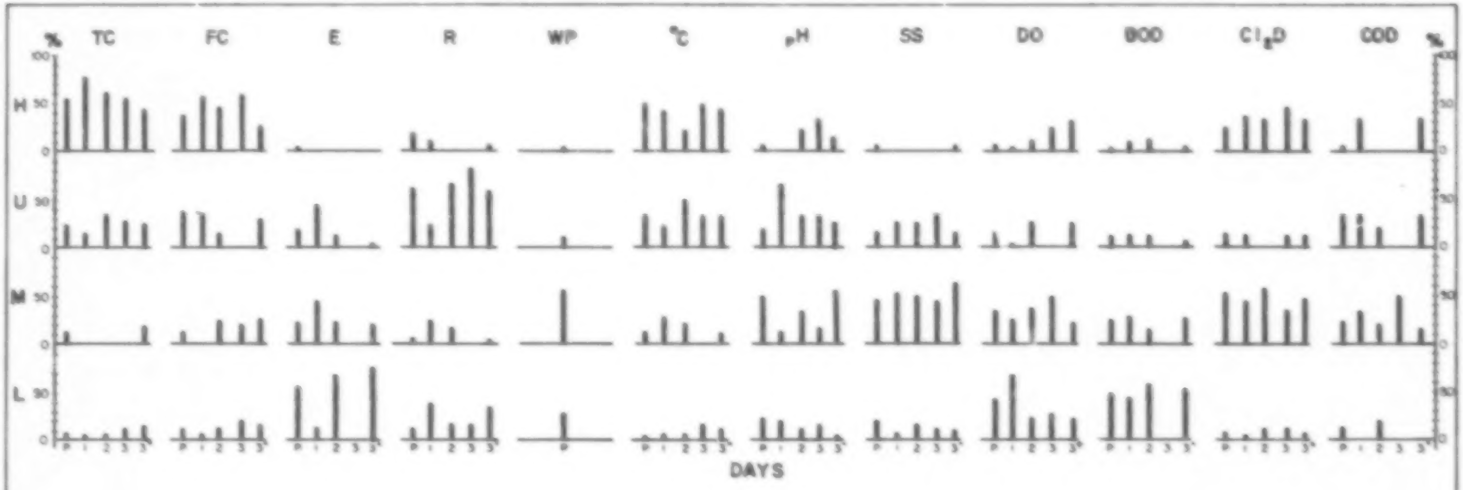


FIGURE 36. PRE-CONSTRUCTION EVALUATION PROGRAM - TEMPERATURE - ARITHMETIC MEAN vs. TIME DPS #3, 4, 7 DISCHARGE



	TC ①	TC ②	FC ①	FC ②	E ①	E ②	R ①	R ②	WP ①	WP ②	°C ①	°C ②	pH ①	pH ②	SS ①	SS ②	DO ①	DO ②	BOD ①	BOD ②	Cl_2D ①	Cl_2D ②	COD ①	COD ②
H	$>10^6$	(95)	$>10^5$	(55)	$>10^5$	(1)	>1.00	(28)	$>3\times10^7$	(5)	>27	(67)	>8.0	(13)	>50	(11)	>7.5	(32)	>30	(9)	>4.0	(59)	>100	(6)
U	10^5-10^6	(42)	10^4-10^5	(45)	10^4-10^5	(12)	.10-1.00	(108)	10^7-3×10^7	(36)	23-27	(53)	7.6-8.0	(33)	30-50	(38)	5.0-7.5	(36)	20-30	(17)	3.3-4.0	(25)	60-100	(21)
M	10^4-10^5	(21)	10^3-10^4	(24)	10^3-10^4	(18)	.05-.10	(16)	10^6-10^7	(146)	19-23	(22)	7.2-7.6	(49)	10-30	(103)	2.5-5.0	(56)	10-20	(43)	2.0-3.3	(97)	30-60	(14)
L	$<10^4$	(17)	$<10^3$	(19)	$<10^3$	(46)	<.05	(28)	$<10^6$	(77)	<19	(11)	<7.2	(17)	<10	(28)	<2.5	(84)	<10	(90)	<2.0	(16)	<30	(5)
TOT. No. OF RD'GS		175		143		77		180		264		153		112		180		208		159		197		46

LEGEND

TC - TOTAL COLIFORM
FC - FECAL COLIFORM
E - ENTEROCOCCI
R - RAINFALL
WP - WATER PUMPED
°C - TEMPERATURE
SS - SUSPENDED SOLIDS
DO - DISSOLVED OXYGEN

BOD - BIOCHEMICAL OXYGEN DEMAND
Cl_2D - CHLORINE DEMAND
COD - CHEMICAL OXYGEN DEMAND
pH - HYDROGEN-ION ACTIVITY
H - HIGH
U - UPPER
M - MIDDLE
L - LOW

P - PUMPING DAY
1 - PUMPING DAY "1
2 - PUMPING DAY "2
3 - PUMPING DAY "3
3* - PUMPING DAY "3*
① - RANGE
② - No. OF READINGS

PARAMETER LEVELS-% vs. DAY
D.P.S. No 7 DISCHARGE

FIGURE 37. DPS #7 PRE-CONSTRUCTION EVALUATION PROGRAM - PARAMETER LEVELS - % vs. DAY

reduction in time, if values were followed in days after pumping, due to the normal satisfaction of these damands. There were no other correlations evident.

After all groupings had been made, no analysis of variance could be run because none of the groupings of data had a sufficient number of readings to fill a factorial arrangement. This was evident during the attempt to correlate total coliform with dissolved oxygen, suspended solids, and temperature. When two time factors, diurnal and seasonal variation, are included in a four level factorial design 4^5 or 1024 data sets would be required if a controlled experiment is to be run. Even a simple two level factorial design would require 2^6 or 64 data sets. A sorting program provided approximately 60 data sets per pumping station which included at least three of the variables. Unfortunately, even with these sets there were many replications and omissions due to the random nature of the pumping and the variables. Thus, even a two-level factorial arrangement cannot be carried out for the four parameters involved. After consideration of the data by day and level it was decided not to run the variables as simple factors since no correlation other than those already noted would be found.

The lack of ordered values was caused by the stochastic nature of the initial conditions of the parameters in the suction bay of the pumping station. The initial conditions are stochastic due to the dependency on rainfall and to the continually changing characteristics of the drainage area. Besides causing the lack of data points in the subgroups, this means that the system being sampled is itself in constant change. Hence, it was felt that an analysis of variance was not indicated for finding relationships between and among the parameters of the Pre-Construction Evaluation Program.

Ultimately, the main obstacle encountered in all attempts of analysis of the data was the stochastic nature of the drainage system. The fact that this was not recognized when the initial data sampling programs were formulated resulted in the collection of a great deal of data which had limited value and was useful only to provide base line level of parameters for the Post-Construction Program.

Pre-Construction Evaluation Results

The object of the Pre-Construction Evaluation Program was to provide a characterization of the quality of the pumped storm water, outfall canal water, and lake water. This was accomplished. However, attempts to deterministically establish relationships between total coliform and other parameters that could be used in controlling the application of disinfectant in the Post-Construction Program were not successful.

The analysis of the data was begun by compiling, tabulating, and plotting the data. From the plots of the data, several immediate observations were possible. The coliform levels were very high in each outfall canal with a large percentage of the total coliform readings above 1000 org/100 ml. Even more polluted, bacterially, were the suction bays at the pumping stations. Also, the fecal coliform readings seemed to stay in constant proportion to the total coliform readings. Concurrently, other parameters traditionally used in indicating pollution were at very low values. However, the values represent standing as well as pumped water and thus were expected to be lower.

To give a more quantitative measure to these observations, computer programs to calculate intensity-frequency data, means, and standard deviations were written and run. The means and standard deviations of the chemical and physical parameters are given in Table 8.

It was found that the bacteriological pollution was great with 99% of the total coliform readings on the suction side of the pumping stations and 92.8% of the total coliform readings in the outfall canals exceeding a level of 1000 org/100 ml. The water in the suction bays was more bacterially polluted than in the corresponding outfall canal where dilution by lake water takes place. The magnitude of the bacterial pollution is also indicated in Table 7. (pg. 76)

The relationship between total coliform and fecal coliform levels was of interest since the five year base period data had demonstrated the possibility of a ten to one relationship between the two parameters. A program to calculate the ratio of total and fecal coliform produced a mean value with a standard deviation of 47.2. However, after re-evaluating the curves, a correlation was sought between the characteristics of the $\log_{10}$ transformation of the total and fecal coliform readings. This was successful with correlations for each station being in the 99% or better confidence band. These correlation coefficients are given in Table 9. This fact was useful in planning the laboratory analysis since it indicated that the fecal coliform levels were one order of magnitude less than the total coliform levels. Also, the Five Year Base Period Evaluation had indicated that the nature

TABLE 8

MEANS & STANDARD DEVIATIONS

PRE-CONSTRUCTION EVALUATION DATA

22 MONTH ANALYSIS

	3D	4S	4D	7S	7D	10S
WATER PUMPED - cfd						
Weight	82,953,592,799		18,456,172,800		83,754,444,694	87,380,336,158
Mean [ft^3]	3,682,505		5,377,672		5,084,161	3,111,835
Std. Dev.	7,154,522		6,122,526		7,785,217	3,579,620
RAINFALL - in.						
Mean	0.47		0.53		0.52	0.50
Std. Dev.	0.61		0.67		0.70	0.71
BOD - mg/l						
Mean	8.3	6.7	7.9	15.2	11.7	9.6
Std. Dev.	6.6	4.9	6.8	11.3	8.7	6.5
COD - mg/l						
Mean	72.9	56.3	81.3	76.3	68.3	80.0
Std. Dev.	62.9	37.9	60.1	48.9	44.8	44.4
DO - mg/l						
Mean	4.3	4.3	5.4	2.8	4.5	5.2
Std. Dev.	2.4	4.0	2.0	1.8	3.1	2.1
Cl_2 DEMAND-mg/l						
Mean	3.3	3.4	3.5	3.3	3.5	3.6
Std. Dev.	1.4	0.9	1.4	1.1	2.4	1.5
pH						
Mean	7.3	7.7	7.6	7.6	7.6	7.6
Std. Dev.	0.4	0.4	0.4	0.3	0.4	0.3
SUSPENDED SOLIDS - mg/l						
Mean	25.6	27.4	27.1	35.5	25.8	51.3
Std. Dev.	23.7	22.8	37.0	36.6	26.4	32.2
TEMPERATURE - °C						
Mean	25.1	26.6	24.9	24.8	25.6	24.3
Std. Dev.	4.9	5.1	5.2	5.0	4.6	5.8

of the bacterial pollution was different in the Citrus canal. However, as the area changed from a rural to a developed region, the coliform levels increased and the ratio, total to fecal, approximated that in older developed regions.

The visual observation of very low levels for non-bacterial parameters were corroborated. As an example, the suction bay at DPS #7 has the highest level of bacterial and chemical pollution of any pumping station. However, BOD, COD, and suspended solids levels were all seen to be relatively low. Only one BOD reading in 171 samples was > 50 mg/l, one COD reading in 43 samples was > 175 mg/l, and nine suspended solids readings in 185 samples were > 100 mg/l. The levels varied from station to station, but all were very low.

Several other parameters were also studied. pH levels varied with 90% of the readings between 7.2 and 8.0. Dissolved oxygen data indicated that 93% of the readings were above 2 mg/l. From the temperature intensity-frequency curves, it was noted that approximately 75% of the readings were taken when the temperature was above 25%C.

POST-CONSTRUCTION EVALUATION PROGRAM

General

Following completion of construction, a sampling program was carried out to study the effectiveness and determine the cost of coliform reduction by hypochlorination. The post-construction evaluation phase continued the weekly canal sampling program of the pre-construction program. Lake samples were only taken after storms. Additionally, numerous water samples were taken during low and high volume pumping operations while NaOCl was being added to the water. These programs were known as, Routine (canal and lake), Storm and Storm Profile Sampling, respectively.

The methodology and sampling points to be used in these three programs were chosen at the beginning of the project. However, from an analysis of the pre-construction data and the method of operation of the pumps at the pumping stations, it became apparent that the sampling programs originally contemplated for the Post-Construction Evaluation Program could not be used to accomplish the goals of the project. In particular, the post-treatment samplers located at DPS #3, #4, and #7 were up to 10,000 ft from the point of discharge of treated storm water into the outfall canals. Thus, they were too far removed

TABLE 9

COLIFORM CORRELATION COEFFICIENTS

	DPS 3S	DPS 4S	DPS 4D	DPS 7S	DPS 7D	Citrus DPS-S
r [TC:FD]	.856	.612	.742	.635	.821	.659
D.F.	161	158	159	157	142	147
r*	.200	.208	.208	.208	.210	.209
r [TC:E]	.695	.419	.625	.508	.594	.279
D.F.	79	88	83	82	76	86
r*	.284	.269	.278	.280	.291	.273

$\text{Characteristic } [\log_{10} \text{FC}] = \alpha \text{ Characteristic } [\log_{10} \text{TC}] + \beta$

$\text{Characteristic } [\log_{10} \text{E}] = \alpha \text{ Characteristic } [\log_{10} \text{TC}] + \beta$

r = Correlation coefficient

r* = Correlation coefficient required for 99% confidence

D.F. = Degrees of Freedom

S - Suction Bay

D - Discharge Bay

from the site of treatment. Due to transport delay, diffusion, and dispersion, treated water from the pumping station would pass the downstream sampler at an unknown time. Also, during low and moderate pumping rate operations, no treated water would ever arrive at the downstream sampler at an unknown time. Also, during low and moderate pumping rate operations, no treated water would ever arrive at the downstream sampler during the period of disinfection. To alleviate this problem, the downstream samplers from DPS #3 and #4 were moved to DPS #7 and located so that any mode of operation at the pumping station would cause water to be sampled at least once at a downstream sampler location. The result of these changes was the location of a complete storm profile facility at DPS #7 with a secondary site at the St. Charles pumping station. Only storm operation and routine data were taken at DPS #3 and DPS #4.

The results of the routine sampling program demonstrated that the overall chemical and physical characteristics of the water in the outfall canals had not substantially changed since the 22 month Pre-Construction Evaluation Program. However, the long term fecal coliform levels at the pumping stations had decreased due to the feeding of NaOCl. The storm profiles run at DPS #7 showed conclusively that it was possible to reduce the total and fecal coliform densities to extremely low levels, less than 10 org/100 ml, for short periods of time in the outfall canals. However, once treatment had ceased, total coliform densities quickly recovered to those levels present in the outfall canals prior to pumping and disinfection. Fecal coliform densities also recovered but to a lesser degree. Basic microbiological theory indicated that the subsequent regrowth of indicator coliform is an expected phenomenon. However, it should be noted that the important effect of decreasing the total number of human specific pathogens in the water should have been provided by disinfection. If this is the case, the human specific pathogen levels in the treated raw storm water would have been greatly reduced and it could be assumed that the relatively harsh environmental conditions in the outfall canals preclude regrowth of the pathogens to a dangerous level. This is a point that requires further study even though it appears to be the reason for diminished fecal coliform regrowth in aftergrowth studies and lower long term coliform levels in the outfall canals. Also, it is important to note that the significance of the indicator coliform group levels is radically altered once disinfection has occurred. After disinfection their presence no longer provides the same measure of possible pathogenicity of the treated storm water.

Sampling Programs

Routine Sampling

Routine sampling took place in the outfall canals on Monday, Wednesday, and Friday morning of each week. Samplers in the outfall canals at DPS #7 and St. Charles were operated and took five samples. The samples were composited and bacterial and chemical values were derived. Grab samples were taken at DPS #3 and #4. Values were found for the following parameters:

Total coliform
Fecal coliform
DO
Total suspended matter
pH
Chlorine demand
Nitrogen (ammonia)
Salinity
Chemical oxygen demand

Data taken during routine sampling was analyzed and compared with the results of the 22 month Pre-Construction Evaluation Program. Specific areas of interest were changes in parameter levels which could be attributed to disinfection as well as changes in the characteristics of the drainage area.

Storm Sampling

Storm sampling during NaOCl feed and low pumpage rates was carried out at DPS #3, #4 and #7 and St. Charles. A low level pumpage period was defined as any storm pumping which consisted of a pumpage rate less than 500 cfs for a period of thirty minutes. The purpose of the storm sampling program was to characterize the storm water during the initial phases of storm water pumpage. By characterizing the storm water during the period of treatment, the storm profile results from DPS #7 could be utilized at DPS #3 and #4 in order to treat the water in an optimum manner. During storm operations, samples were taken at each rate of pumping and composited to provide samples for analysis. Samples were analyzed for:

Total coliform
Fecal coliform
Salinity
Temperature
Nitrogen (ammonia)
COD
Enterococci
Chlorine demand
pH
Total suspended matter
Total solids
Volatile suspended matter
BOD

Once the immediate bacterial, chemical, and physical parameters were determined, a 100 ml sample was stored at 20°C to determine aftergrowth of coliform and enterococci. Lake samples were taken from the shore as soon as possible after cessation of the storm.

Data from the storm sampling program was compared with the influent characteristics of storm profiles at DPS #7 as well as the data available from the Pre-Construction Evaluation Program.

Storm Profile Sampling

A storm profile consisted of numerous samples taken during the period of NaOCl feed and high volume pumpage operation. A high volume pumpage operation was defined as greater than 500 cfs for one-half hour at the pumping station.

Sixteen storm profile samples were taken at DPS #7. It was also hoped that storm profiles could be taken at the St. Charles pumping station. However, the unmanned operation of the station, extensive equipment failure, and vandalism at the St. Charles station (pg58) resulted in a complete lack of storm profile data from the St. Charles station. One preliminary profile had been taken in 1970, but the data collected was not in the format of the storm profiles taken during the Post-Construction Evaluation Program.

Four samplers, A, B, C, and D were in operation during the disinfection and pumping operation at DPS #7. Samples were taken (1) at four minute intervals at A in the suction bay and at B in the discharge bay immediately downstream of the station; (2) at 15 minute intervals at C, 0.25 miles downstream; and (3) at 30 minute intervals at D, 1.50 miles downstream. The location of the sampling points is shown in Figure 38. As previously noted, no storm profiles were taken at DPS #3, #4, or St. Charles.

Storm profile samples were analyzed for the following parameters:

Total coliform
Fecal coliform
pH
Temperature
Nitrogen (ammonia)
Salinity
Total suspended matter

The bacterial and chemical results for A and B were derived by compositing samples while C and D results are discreet values. The compositing at A and B was carried out in the

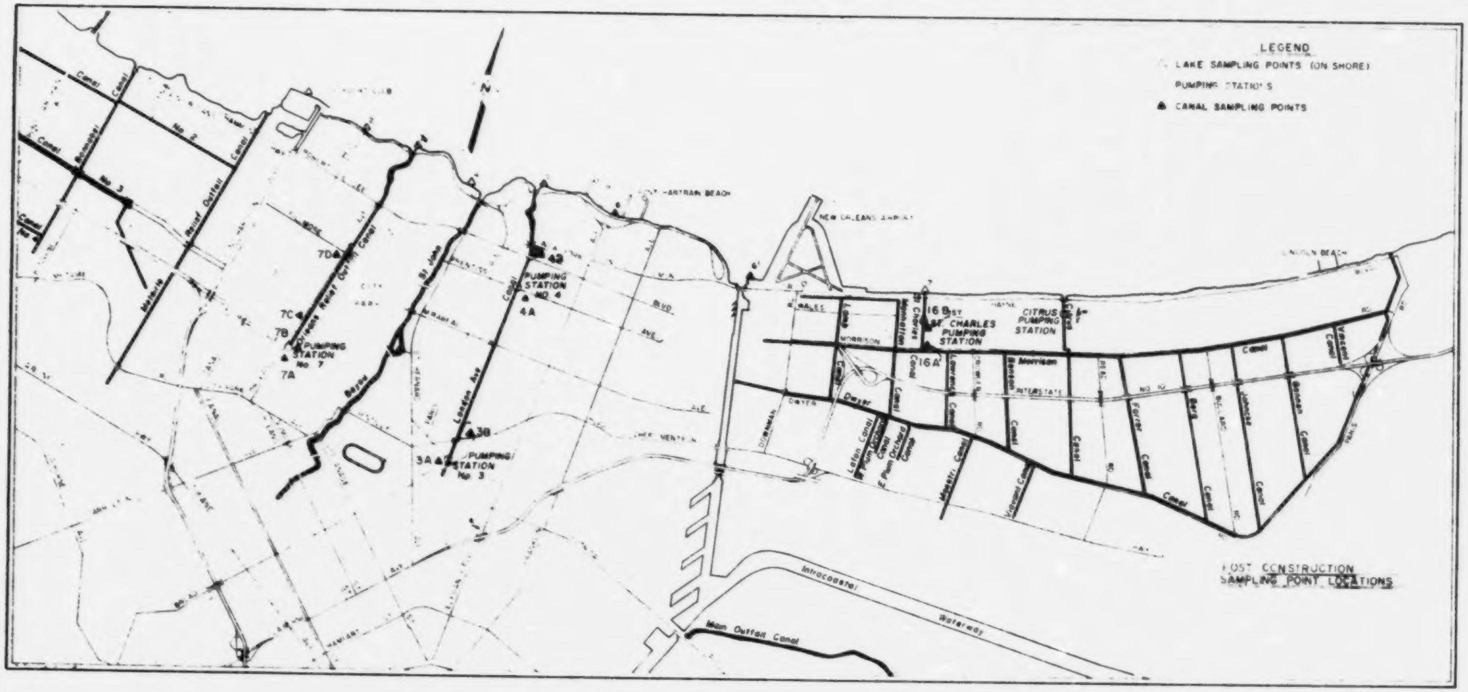

LEGEND
LAKE SAMPLING POINTS (ON SHORE)
PUMPING STATIONS
CANAL SAMPLING POINTS
POST CONSTRUCTION SAMPLING POINT LOCATIONS
N
NEW ORLEANS AIRPORT
PONTCHARTRAIN BEACH
LINCOLN BEACH
16 B
ST. CHARLES PUMPING STATION
CITRUS PUMPING STATION
16A
Vincent Canal
Bonnabel Canal
Johnson Canal
Berg Canal
Farrar Canal
Morrison
Benson Canal
Lawrence Canal
St Charles Canal
Manhattan Canal
Lamb Canal
Dwyer Canal
Lafon Canal
E Plum Orchard Canal
Maestri Canal
Vallaman Canal
INTERSTATE
4B
PUMPING STATION No 4
4A
London Ave Canal
3B
3A
PUMPING STATION No 3
St John
Bayou
7D
7C
7B
PUMPING STATION No 7
7A
Orleans Relief Outfall Canal
Metairie Relief Outfall Canal
Bonnabel
Canal No 2
Canal No 3
Intracoastal Waterway
Main Outfall Canal

FIGURE 38. POST-CONSTRUCTION EVALUATION PROGRAM - STORM WATER SAMPLING POINTS

Reproduced from best available copy.

following manner. For the first 32 minutes, samples were composited with a maximum of two samples per composite sample so that the rapidly changing characteristics of the water during the initial stages of disinfection would not be obscured. Thereafter, a maximum of seven samples were used per composite. The composite value was plotted at a mean time determined by averaging the sampling times of the individual samples. As an example, samples 1 and 2 at A would be composited and plotted at t = 6 min, samples 9 ghrough 16 would be composited and plotted at t = 45 min. Chlorine residual and NaOCl feed rate values were taken from the four inch strip chart recordings on the control panel. Water pumpage data were taken from the pumping records at the pumping station. Values for total suspended matter were derived for initial and final samples only.

The magnitude of the amount of water treated and representative results for the sixteen storm profiles are given in Table 10. As can be seen, $<1041.32\times10^6$ gallons of water were treated with greater than 35×10^3 gallons of NaOCl. The operating characteristics of the pumping station prevented all water from being treated on certain occasions. Since the top priority of the stations is to prevent flooding, the operation would begin pumping prior to notifying the treatment and sampling personnel. Thus, large quantities of water would be pumped before treatment began. Because of this fact, the largest single treatment episode was not on May 12, 1972, but July 20, when 68.19×10^6 gal. of storm water was treated with 8143 gal. of NaOCl. Excellent maximum coliform removals were attained with average chlorine residuals of 0.19 mg/l to 0.82 mg/l. Average chlorine residuals were calculated by taking the time average of the chart recording. The maximum removal rates were calculated by using the average input coliform reading at sampler A and the minimum coliform value at either sampler B or C, whichever was lower. When samples from A were not available due to sampler intake heads breaking, prime point B was used as the input parameter. Coliform removal rates improved at the end of the project due to two factors. One was the apparent familiarity of operators with the response of the system, especially with respect to the time lags inherent in the feedback loops. Secondly, it was found that a period of prechlorination prior to initiation of pumping alleviated the original "slug" of high coliform levels (pg.114).

TABLE 10

POST CONSTRUCTION STORM WATER TREATMENT EPISODES

Date	Storm Water Treated [galx10^6]	NaOCl Used [gal]	NaOCl Strength [gram/l]	Avg. ClR [mg/l]	Max. Total Coliform Removal Rate [%]	Max. Fecal Coliform Removal Rate [%]
Dec. 7, 1971	49.4	--	86.5	--	--	--
Feb. 7, 1972	17.07	1481	64.3	.55	99.96	99.9
Mar. 2, 1972	67.96	--	76.6	--	99.84	99.99
Mar. 9, 1972	36.15	--	75.2	--	99.99	99.8
Mar. 19, 1972	59.81	644	76.6	--	99.99	99.99
May 11, 1972	58.23	1327	62.4	.23	99.65	99.95
May 12, 1972	312.65^1	3919	62.4	.31	*	*
June 9, 1972	17.29	1197	57.4	--	*	*
July 5, 1972	146.71^1	3727	60.9	.19	99.98	99.9
July 12, 1972	39.30	2592	49.6	.32	99.9	99.9
July 13, 1972	61.98	2681	49.6	.27	99.99	99.99
July 20, 1972	68.19	8143	47.5	.82	99.9998	99.998
Sept. 30, 1972	14.82	2346	58.9	.78	99.9998	--
Oct. 22, 1972	76.72	6788	53.2	.49	99.997	99.998
Nov. 4, 1972	15.04	854	51.8	.42	99.99999	99.999
Total	1041.32	>35,699.				

* MINIMUM VALUE NOT AVAILABLE

1 ALL STORM WATER NOT TREATED

The data taken at DPS #7 showed that it was possible to reduce the total colifor level in the outfall canal below 1000 org/ 100 ml as required by the Louisiana State Board of Health. Decreases in fecal coliform levels were commensurate with total coliform level changes. However recovery of both groups of indicator organisms occurred within 24 to 30 hours.

Post-Construction Evaluation Results

Routine Sampling

Routine samples were taken three times a week in the outfall canals at the four pumping stations involved in the project. Values attained were placed on punch cards and statistically analyzed. The chemical and physical results for the Orleans Ave. canal (DPS #7) are shown in Table 11. As can be seen, the average values for the chemical and physical parameters during the Post-Construction Evaluation Program were comparable to those found during the Pre-Construction Evaluation Program. Salinity and nitrogen (ammonia) values were not taken during the pre-construction program. However, it can be seen that the water is predominately fresh water although there are some dissolved minerals present. The average temperature in the outfall canals for the two programs was almost the same with no significant difference. Nitrogen (ammonia) is seen to be present at a very low level. COD levels did not vary appreciably between the two sampling programs, and neither have Cl_2D, pH, DO, or total suspended matter levels. This indicates that the basic chemical and physical nature of the storm water in the Orleans Avenue Canal (DPS #7) did not change.

The only parameters which have changed during the Post-Construction Evaluation Program are the levels of total and fecal coliforms (Figures 39 to 44). As can be seen, the level of fecal coliform has dropped to less than that present during the Five Year Base Period in each outfall canal. This is to be expected from the treatment of the polluted storm water as fecal coliform organisms do not regrow to the same extent as total coliform. Also, total coliform levels in the Orleans Avenue Canal (DPS #7) have been lowered considerably, while remaining the same in the London Avenue Canal (DPS #3 and #4) and rising slightly at St. Charles. The decreased level in the Orleans Avenue Canal (DPS #7) is due to the fact that all water pumped by DPS #7 was treated with NaOCl while only a portion of the storm water pumpage at the other stations was disinfected. Evidently this increased level of treatment at DPS #7 and served to lower the long term total coliform levels. The total coliform increase at St. Charles was probably due to the development of the area, with the attendant higher runoff coefficient. The statistical chemical and physical results of the routine sampling program for DPS #3, #4, and St. Charles

TABLE 11

DPS #7 - PRE AND POST-CONSTRUCTION EVALUATION PROGRAM:

MEANS AND STANDARD DEVIATIONS OF CHEMICAL AND PHYSICAL PARAMETERS

	PRE-CONSTRUCTION		POST-CONSTRUCTION		
	Mean (A)	SD	Mean (A)	SD	Mean (G)
SAL	—	—	1853.1	2943.6	827.7
TEMP	25.6	4.6	24.2	6.1	21.3
NH_3	—	—	0.6	0.8	0.2
COD	68.3	44.8	77.0	39.4	67.7
Cl_2D	3.5	2.4	3.5	0.9	3.3
pH	7.6	0.4	7.2	0.5	7.2
DO	4.5	3.1	5.7	2.3	5.1
TSM	25.8	26.4	28.0	16.3	23.6

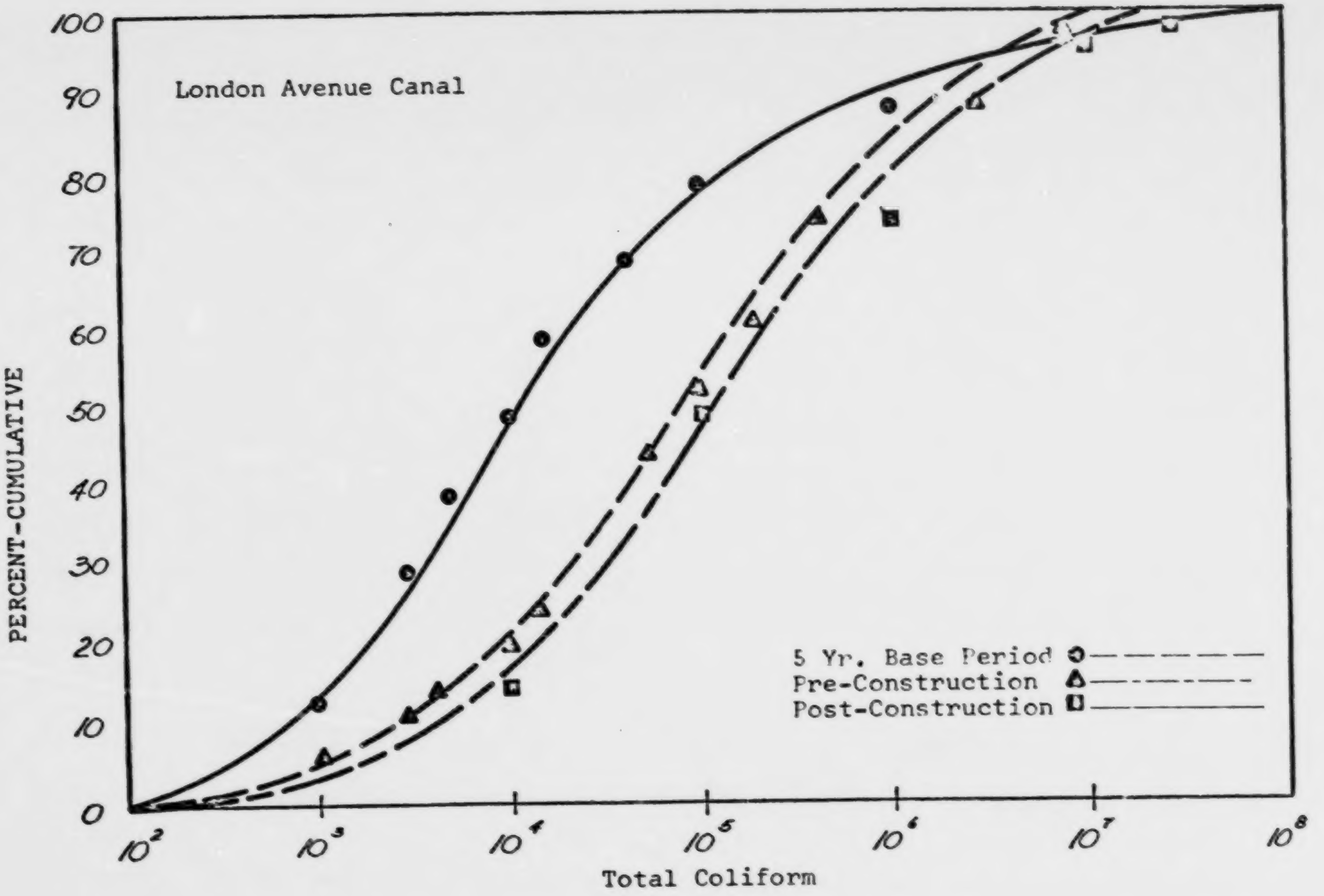


FIGURE 39. LONDON AVE. CANAL (DPS #3 & 4) TOTAL COLIFORM LEVELS FIVE YEAR BASE PERIOD, PRE-CONSTRUCTION EVALUATION & POST-CONSTRUCTION EVALUATION

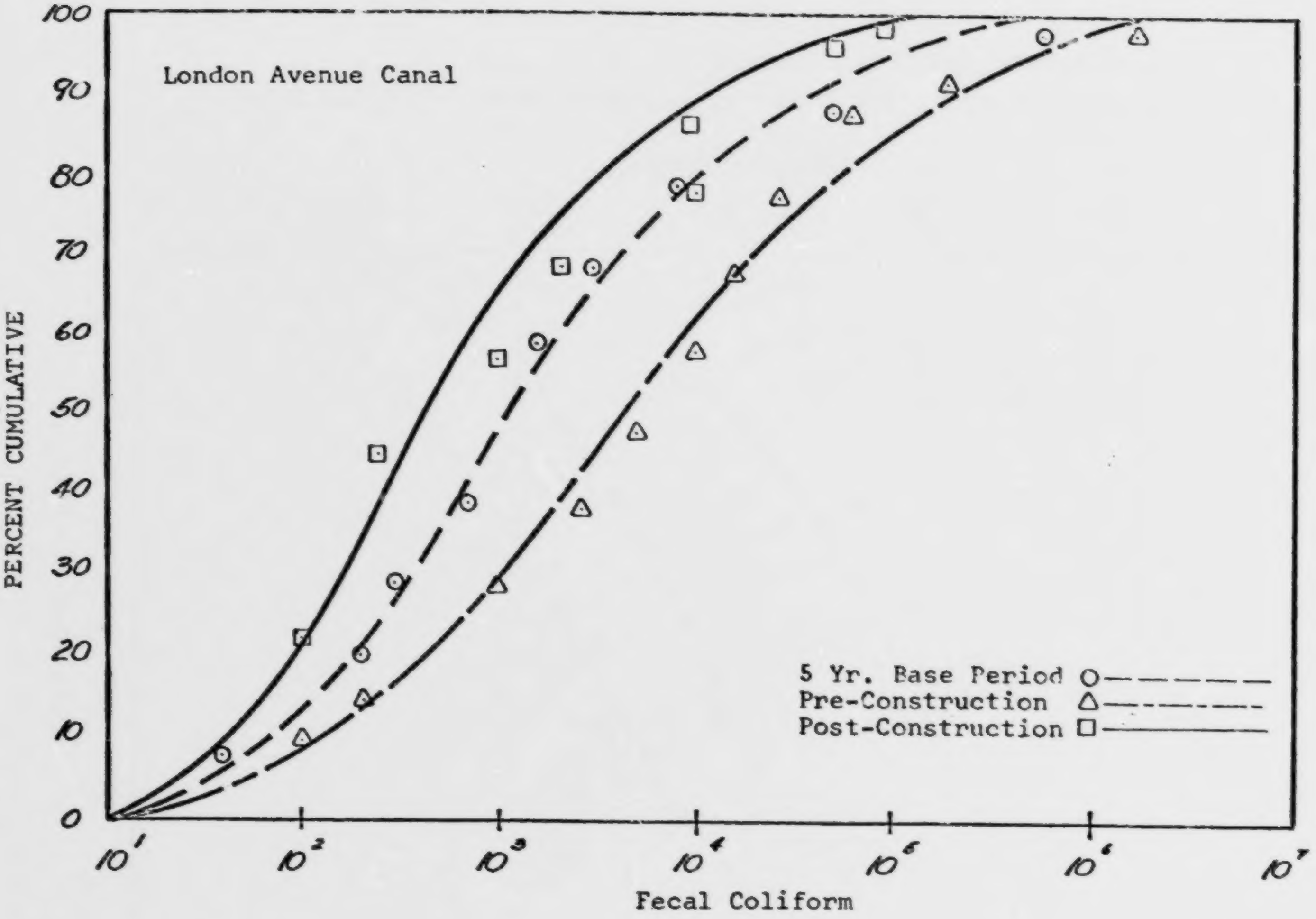


FIGURE 40. LONDON AVE. CANAL (DPS #3 & 4) FECAL COLIFORM LEVELS FIVE YEAR BASE PERIOD, PRE-CONSTRUCTION EVALUATION & POST-CONSTRUCTION EVALUATION

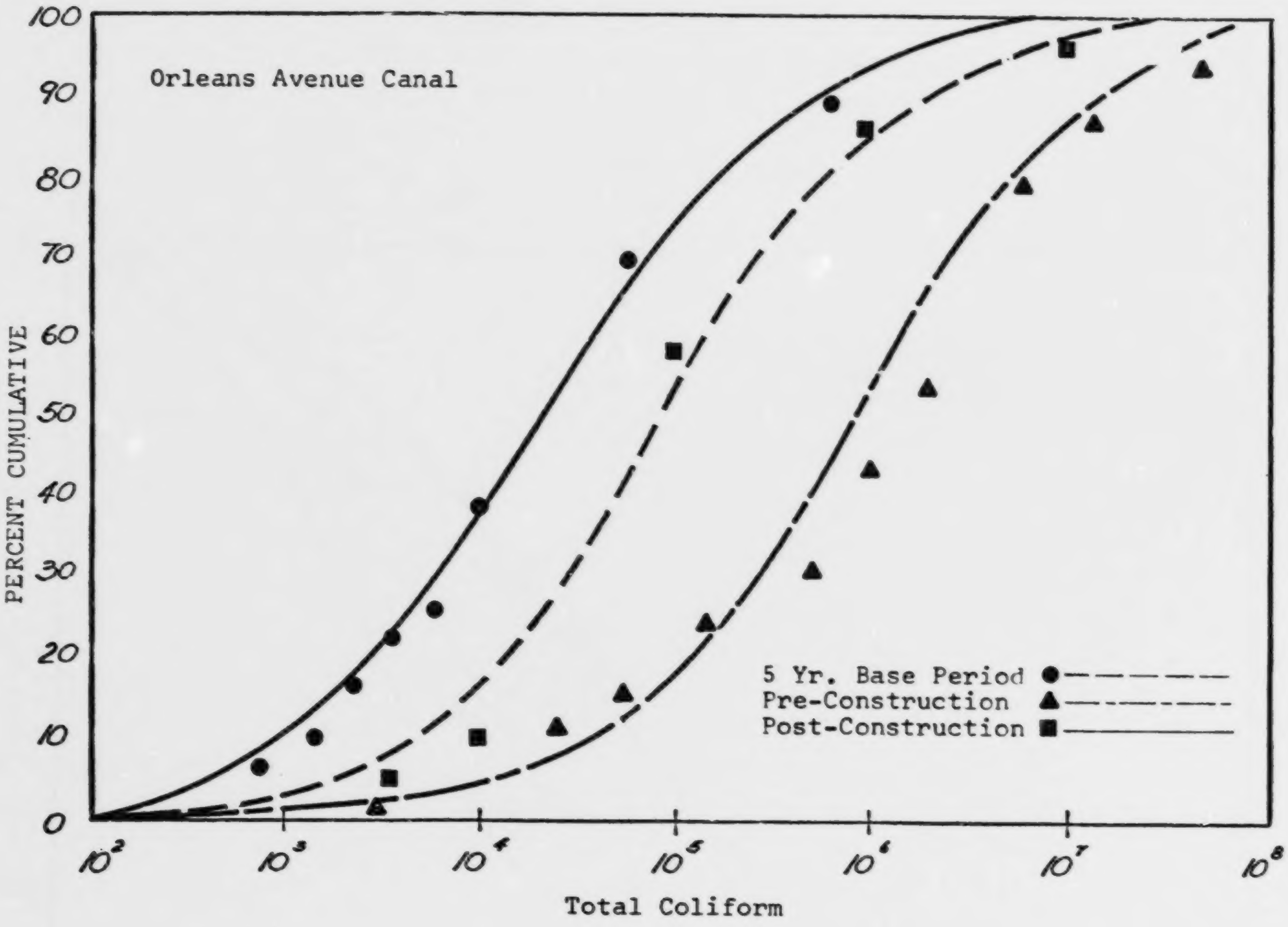


FIGURE 41. ORLEANS AVE. CANAL (DPS #7) TOTAL COLIFORM LEVELS FIVE YEAR BASE PERIOD, PRE-CONSTRUCTION EVALUATION & POST-CONSTRUCTION EVALUATION

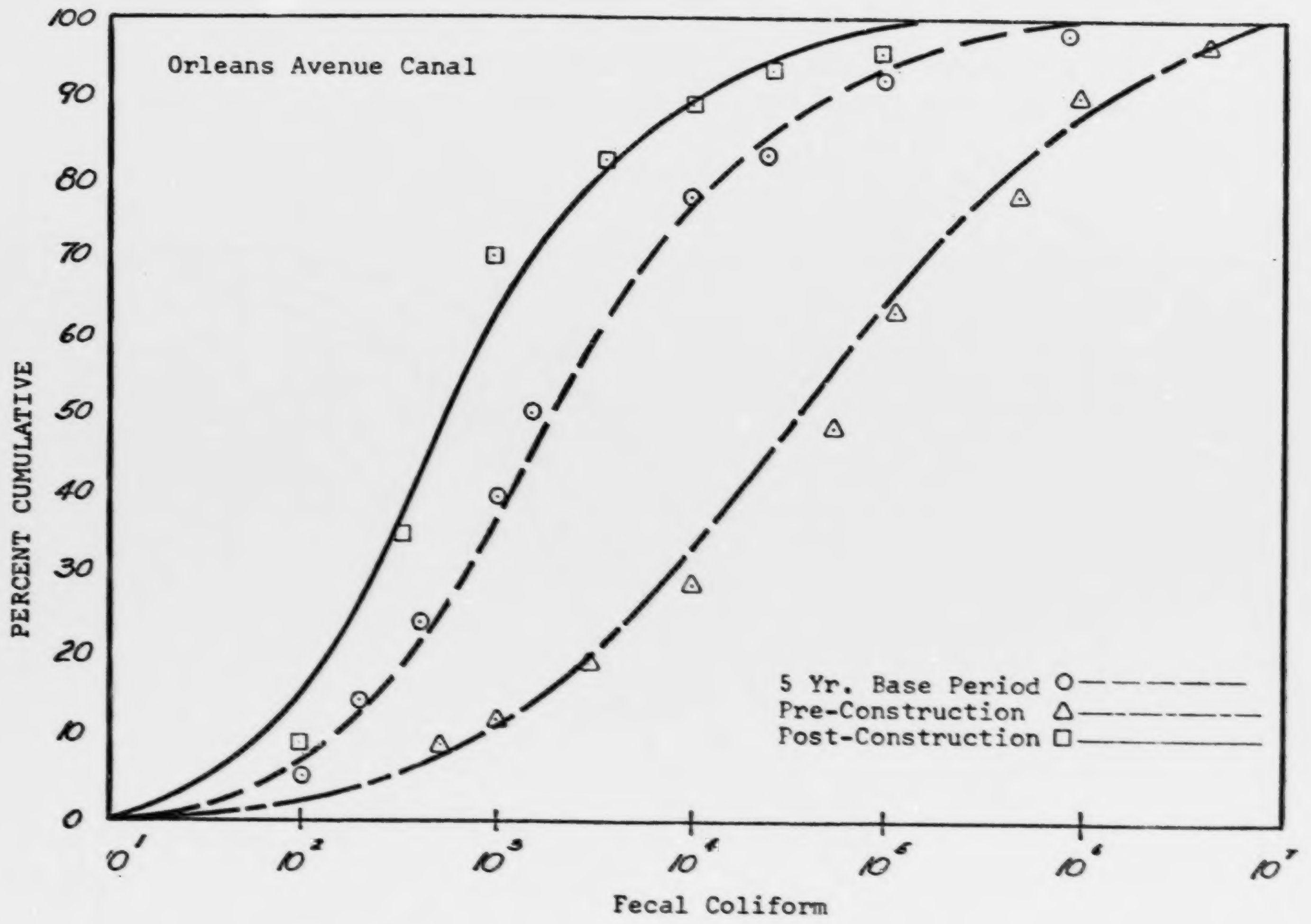


FIGURE 42. ORLEANS AVE. CANAL (DPS #7) FECAL COLIFORM LEVELS FIVE YEAR BASE PERIOD, PRE-CONSTRUCTION EVALUATION & POST-CONSTRUCTION EVALUATION

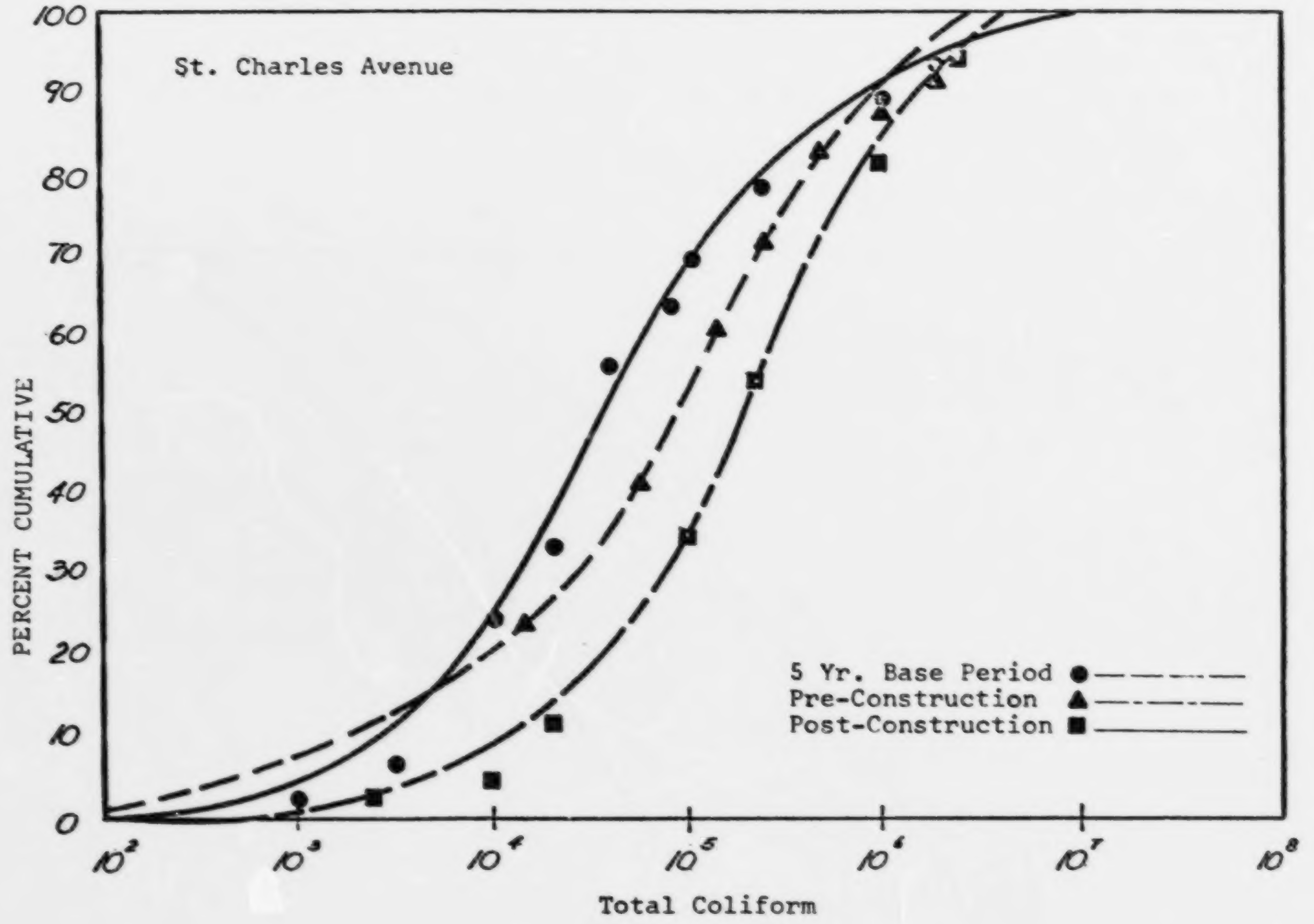


FIGURE 43. ST. CHARLES REACTION BASIN (ST. CHARLES DPS) TOTAL COLIFORM LEVELS FIVE YEAR BASE PERIOD, PRE-CONSTRUCTION EVALUATION & POST-CONSTRUCTION EVALUATION

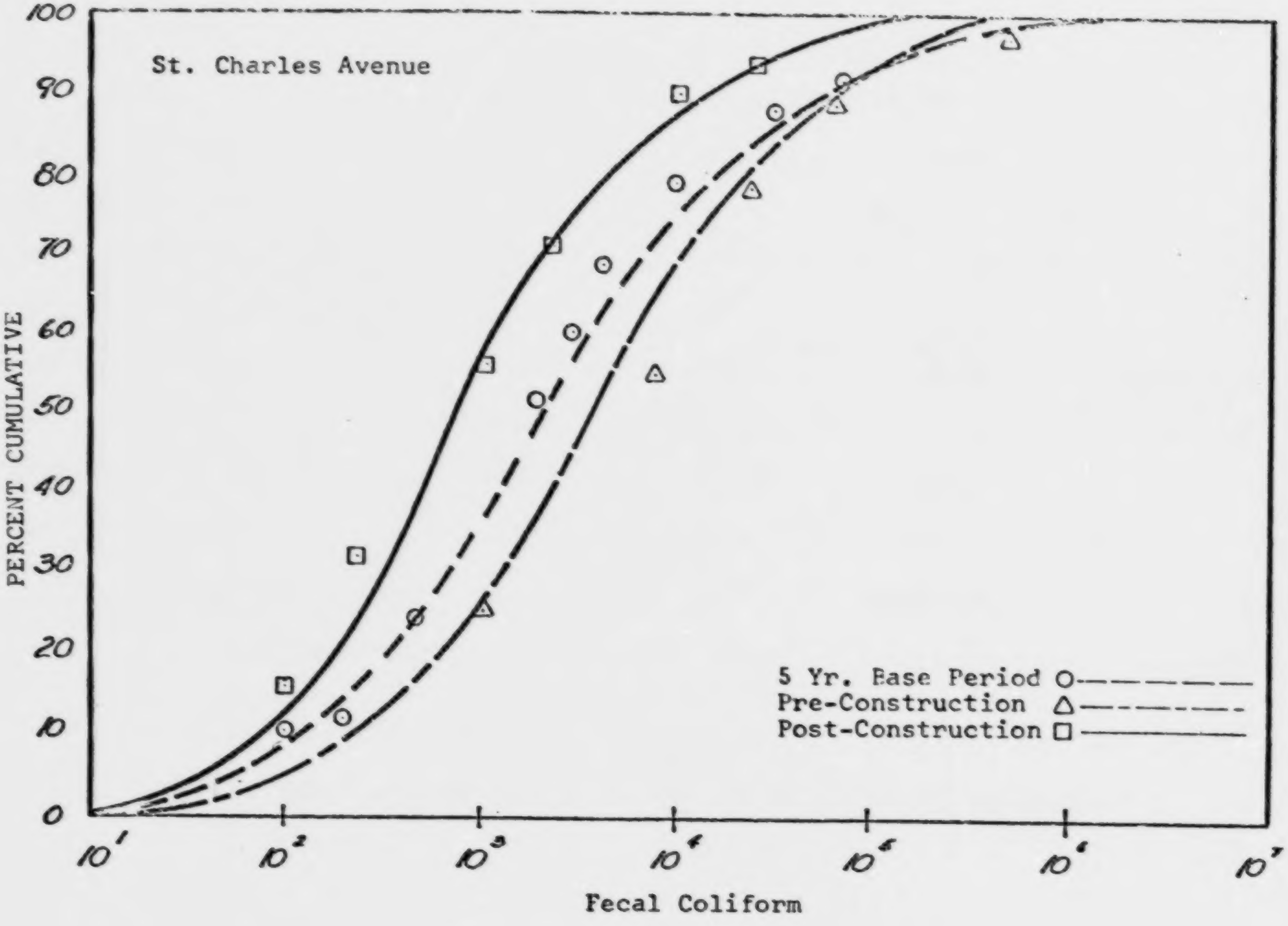


FIGURE 44. ST. CHARLES REACTION BASIN (ST. CHARLES DPS) FECAL COLIFORM LEVELS FIVE YEAR BASE PERIOD, PRE-CONSTRUCTION EVALUATION & POST-CONSTRUCTION EVALUATION

TABLE 12

DPS #3 - PRE AND POST-CONSTRUCTION EVALUATION PROGRAM:

MEANS AND STANDARD DEVIATIONS OF CHEMICAL AND PHYSICAL PARAMETERS

	PRE-CONSTRUCTION		POST-CONSTRUCTION		
	Mean (A)	SD	Mean (A)	SD	Mean (G)
SAL	—	—	1553.0	2550.2	636.4
TEMP	25.1	4.9	24.0	6.5	23.1
NH_3	—	—	0.4	0.5	0.1
COD	72.9	62.9	71.5	35.6	64.4
Cl_2D	3.3	1.4	3.2	0.9	3.0
pH	7.3	0.4	7.1	0.8	6.6
DO	4.3	2.4	5.1	2.8	3.0
TSM	25.6	23.7	28.4	20.4	22.9

TABLE 13

DPS #4 - PRE AND POST-CONSTRUCTION EVALUATION PROGRAM:
MEANS AND STANDARD DEVIATIONS OF CHEMICAL AND PHYSICAL PARAMETERS

	PRE-CONSTRUCTION		POST-CONSTRUCTION		
	Mean (A)	SD	Mean (A)	SD	Mean (G)
SAL	—	—	1596.3	2470.5	777.2
TEMP	24.9	5.2	24.3	5.6	23.9
NH_3	—	—	0.3	0.3	0.1
COD	81.3	60.1	75.5	37.4	67.6
Cl_2D	3.5	1.4	3.2	0.8	3.1
pH	7.6	0.4	7.2	0.5	7.1
DO	5.4	2.0	5.6	2.8	3.6
TSM	27.1	37.0	27.9	18.3	21.6

TABLE 14

ST CHARLES - PRE AND POST-CONSTRUCTION EVALUATION PROGRAM:

MEANS AND STANDARD DEVIATIONS OF CHEMICAL AND PHYSICAL PARAMETERS

	PRE-CONSTRUCTION		POST-CONSTRUCTION		
	Mean (A)	SD	Mean (A)	SD	Mean (G)
SAL	—	—	1389.8	2269.9	703.7
TEMP	24.3	5.8	24.6	5.0	24.3
NH_3	—	—	2.6	1.1	2.3
COD	80.0	44.4	114.3	36.4	107.1
Cl_2D	3.6	1.5	2.8	0.6	2.7
pH	7.6	0.3	7.2	0.4	7.2
DO	5.2	2.1	3.3	2.1	2.6
TSM	51.3	32.2	37.8	21.3	32.7

are listed in Tables 12 through 14 and show the same properties as the data for DPS #7. Thus, with the exception of lower fecal coliform levels in each outfall canal, lower total coliform levels in the Orleans Avenue Canal (DPS #7), and slightly higher total coliform values at St. Charles, there appear to be no significant long term changes in the parameters due to NaOCl addition. However, the time base for this data is only 17 months and it is possible that long term effects might be demonstrated after years of treatment. Only continued treatment and sampling can provide the answer.

Storm Operation

Operational data was gathered at DPS #3 and #7 during low volume pumpage operations. Data was available from St. Charles and DPS #4, but the amount was not sufficient to provide statistical parameters which would be valid.

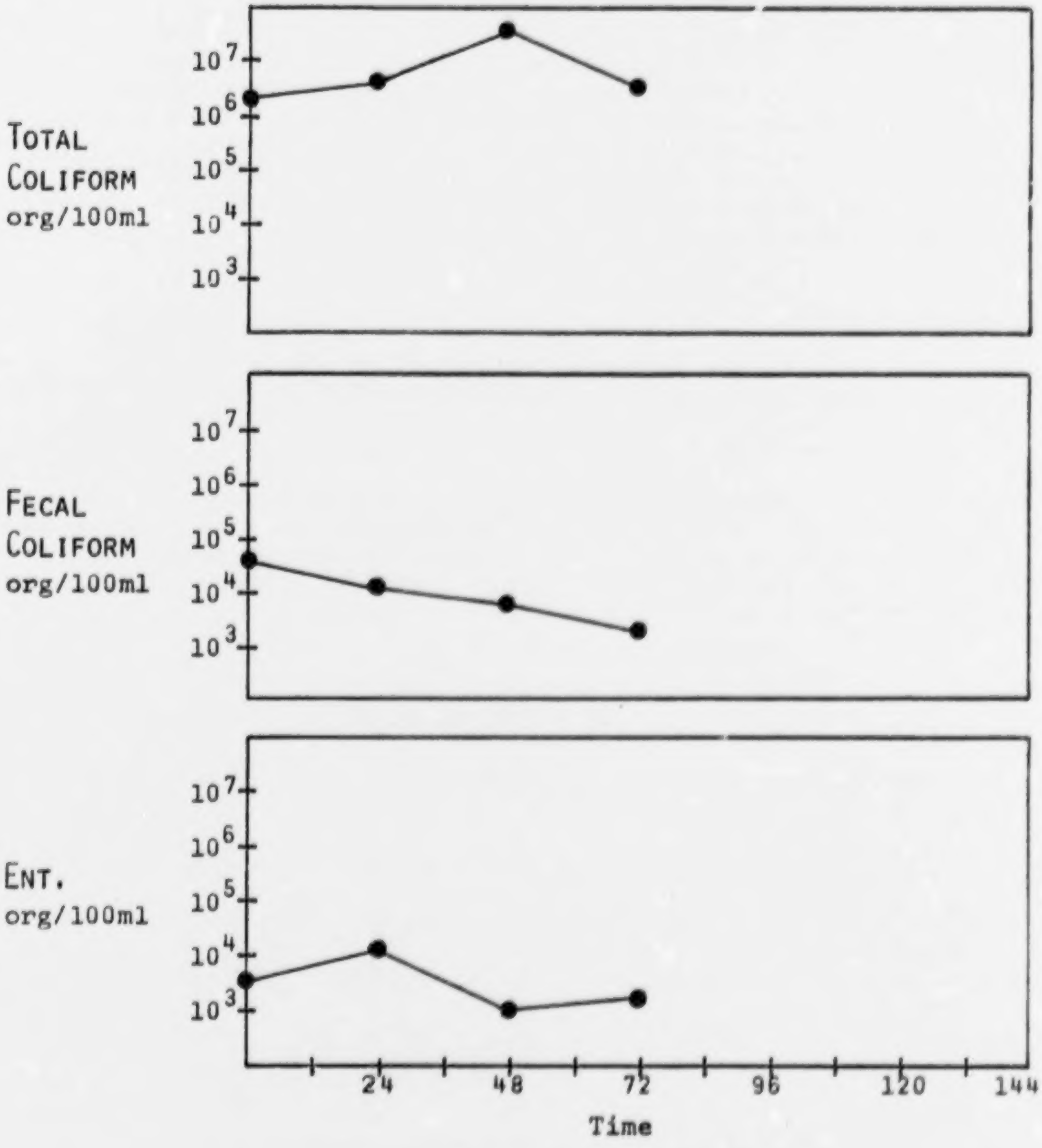
Samples were taken in the suction bay of DPS #3 and #7 at four minute intervals during low volume pumpage rates and composited. Samples were then analyzed for standard sanitary parameters (pg 88). The results for 11 storm sampling episodes from A at DPS #3 are given in Table 15.

TABLE 15

DPS #3 - STORM SAMPLING, BACTERIAL, CHEMICAL, AND PHYSICAL RESULTS

PARAMETER	MEAN	PARAMETER	MEAN
TOTAL COLIFORM org/100ml	1.2×10^7	pH	7.4
FECAL COLIFORM org/100ml	3.7×10^5	TSM - mg/1	228
ENTEROCOCCI org/100ml	5.6×10^4	VSM - mg/1	22
SAL - mg/1	739.0	TOTAL SOLIDS mg/1	2453
COD - mg/1	140.0	NH_3 - mg/1	10
Cl_2D - mg/1	2.4	TEMP - °C	24.4
		BOD	16

As can be seen, there were no significant differences in the parameter levels between the pre and post construction suction bay data. There were slightly elevated COD and TSM values, but these are expected during the initial "flushing" of the drainage system. Results for DPS #7 are comparable as can be seen in Table 16.



POST-CONSTRUCTION AFTER GROWTH STUDY
DPS #3 2-2-72

FIGURE 45. DPS #3 STORM AFTERGROWTH STUDY

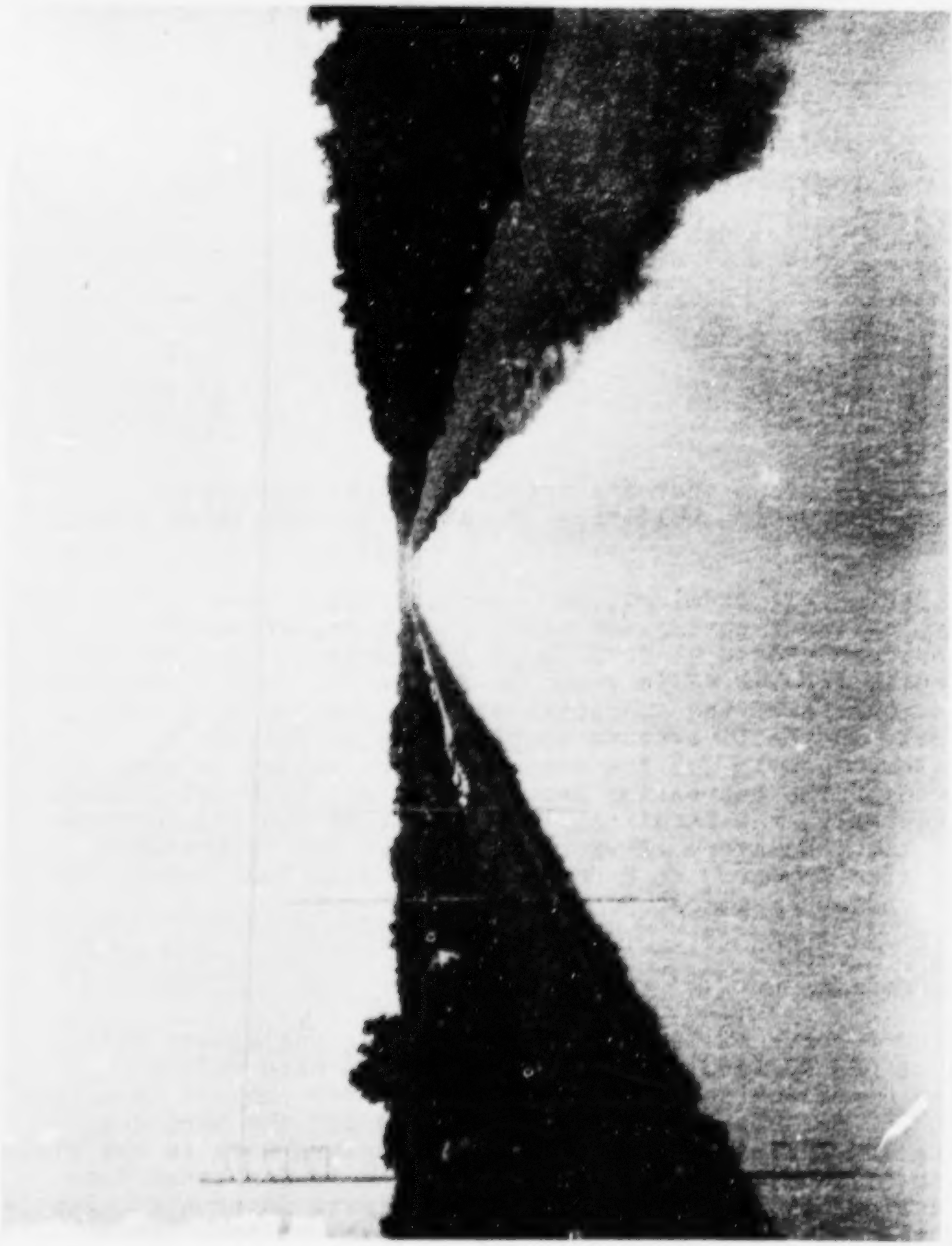


FIGURE 46. DPS #7 - ORLEANS AVE. OUTFALL CANAL

TABLE 16

DPS #7 - STORM SAMPLING, BACTERIAL, CHEMICAL, AND PHYSICAL RESULTS

PARAMETER	MEAN	PARAMETER	MEAN
TOTAL COLIFORM org/100ml	$3.5\text{x}10^7$	pH	6.7
FECAL COLIFORM org/100ml	$2.5\text{x}10^5$	TSM - mg/l	185
ENTEROCOCCI org/100ml	$1.3\text{x}10^4$	VSM - mg/l	--
SAL - mg/l	643	TOTAL SOLIDS mg/l	--
COD - mg/l	71	NH_3 - mg/l	.3
Cl_2D - mg/l	2.5	TEMP - °C	23.3
		BOD	18

It should be noted that the levels of those parameters normally indicating pollution of water are much lower than in sewage.

After bacterial, chemical, and physcial tests were performed on samples taken during the storm operation, aftergrowth samples were stored at 20°C in an incubator. A typical set of results for DPS #3 is shown in Figure 45. The aftergrowth data demonstrated the characteristics of bacterial growth available in the literature as discussed in Section 9. Logarithmic growth for the total coliform values is seen followed by the decreasing growth phase and eventual dieoff. Significantly, the fecal coliform densities did not increase during the laboratory aftergrowth study. The enteroccoci levels also appeared to demonstrate the classical growth and dieoff characteristics.

Storm Profiles

Detailed records of 16 high volume pumping operations were taken at DPS #7 (see Table 10, pg. 91). A high volume pumping operation was defined as storm water pumpage in excess of 500 cfs for more than 30 minutes. During the period of pumping and disinfection, four water samplers were in operation. Sampler A, located at the entrance of the feeder canal into the suction bay, took samples at four minute intervals. Sampler B, in the discharge bay, also took samples at four minute intervals. Further downstream Sampler C, 0.25 miles from the station, took samples at fifteen minute intervals while Sampler D, 1.50 miles from the station, sampled at 30 minute intervals. The location of the samplers can be seen in Figure 17 (pg100). The results of the storm profiles can be explained by the physical characteristics of the drainage system, the empirical disinfection equation, the effects of diffusion and dispersion, and microbiological growth patterns.

NaOCl is fed to the water entering the suction bay at DPS #7 just after passing the intake for Sampler A. The suction bay is relatively large and can act as a storage reservoir. This introduces the first of several time delays, τ_{ab}. This delay is the effective time for treated water from A to reach B. Since there are several different pumps which can operate singly or in combination, τ_{ab} can vary from approximately five to twenty minutes. This first delay factor is extremely important from the standpoint of NaOCl addition since it represents the closed loop delay time for the operator in controlling the residual level. A delay of this magnitude normally causes unstable behavior in a feedback loop.

Once the disinfected water leaves the discharge bay at DPS #7, it flows into the Orleans Avenue outfall canal (Fig. 46). Sampler C, is located 0.25 miles downstream and the volume of water between B, the discharge bay, and C introduces a second delay time, τ_{bc}. The factors influencing τ_{bc} are the rate of storm water pumpage, tidal levels and flow in the outfall canal, channeling of the storm water flow, and diffusive and dispersive effects. The channeling occurs since the discharge bay is divided by partitions which act as short flow nozzles. The delay τ_{bc} can be calculated by comparing the corresponding peaks in the bacterial levels at B and C after correcting for decreased coliform levels at C due to increased NaOCl contact time. A third delay time, τ_{cd}, is introduced by the volume of water between C and D. The delay, τ_{cd}, is influenced by the same factors as τ_{bc}, but tidal, diffusion and dispersion effects are much more important than channeling. Additionally, if the quantity of storm pumpage is not sufficient to displace the water between C and D, then diffusive effects with a time scale of days or weeks predominate. Assuming a constant pumping rate of 550 cfs, and neglecting the other complex factors, the time delays on a volumetric displacement basis at DPS #7 are given in Table 17.

TABLE 17

DPS #7 : VOLUMETRIC TIME DELAYS

SAMPLING POINTS

	A - B	B - C	C - D	B - D
τ τ(min)	~8-20	36	180	216

The actual decrease of bacterial levels by NaOCl is governed by the emperical relationship.

$$E \cong t\ c^n$$

Where E is the kill efficiency, t is the contact time during which a residual is present, c is the concentration of available disinfectant, and n is the constant of the reaction. It should be noted that this equation holds only after the chlorine demands of all other reducing compounds are satisified and a residual is present.

When NaOCl is added to the storm water it is immediately **hydrolyzed.**

$$NaOCl + H_2O \rightleftarrows NaOH + HOCl$$

The HOCl ion then equilibrates with its dissociated charged ions.

$$HOCl \rightleftarrows H^+ + OCl^-$$

It is generally accepted that the neutral HOCl particle disrupts the cell to a greater extent than the OCl^- ion. The HOCl molecule is thought to interfere with cell respiration by reacting with enzymes and this destroys the cell. The dissociation constant for HOCl is dependent on temperature, pH and levels of nitrogenous reducing compounds. Elevated temperatures shift the equilibrium to the right as do alkaline pH levels. Nitrogenous compounds convert HOCl to chloramines which are much less effective as disinfectants. This effect is also dependent on pH with the maximum conversion occurring at pH = 8.4.

The results of a storm profile taken at DPS #7 on November 13, 1972 are given in Figures 47 to 49. This storm profile was selected because most of the various facets of a treatment episode are demonstrated. The remaining storm profiles are included in the Appendix.

The most difficult aspect of the disinfection operation is the maintenance of a pre-determined residual level. The fluctuations in the Cl_2R curve are typical (Figure 47). The

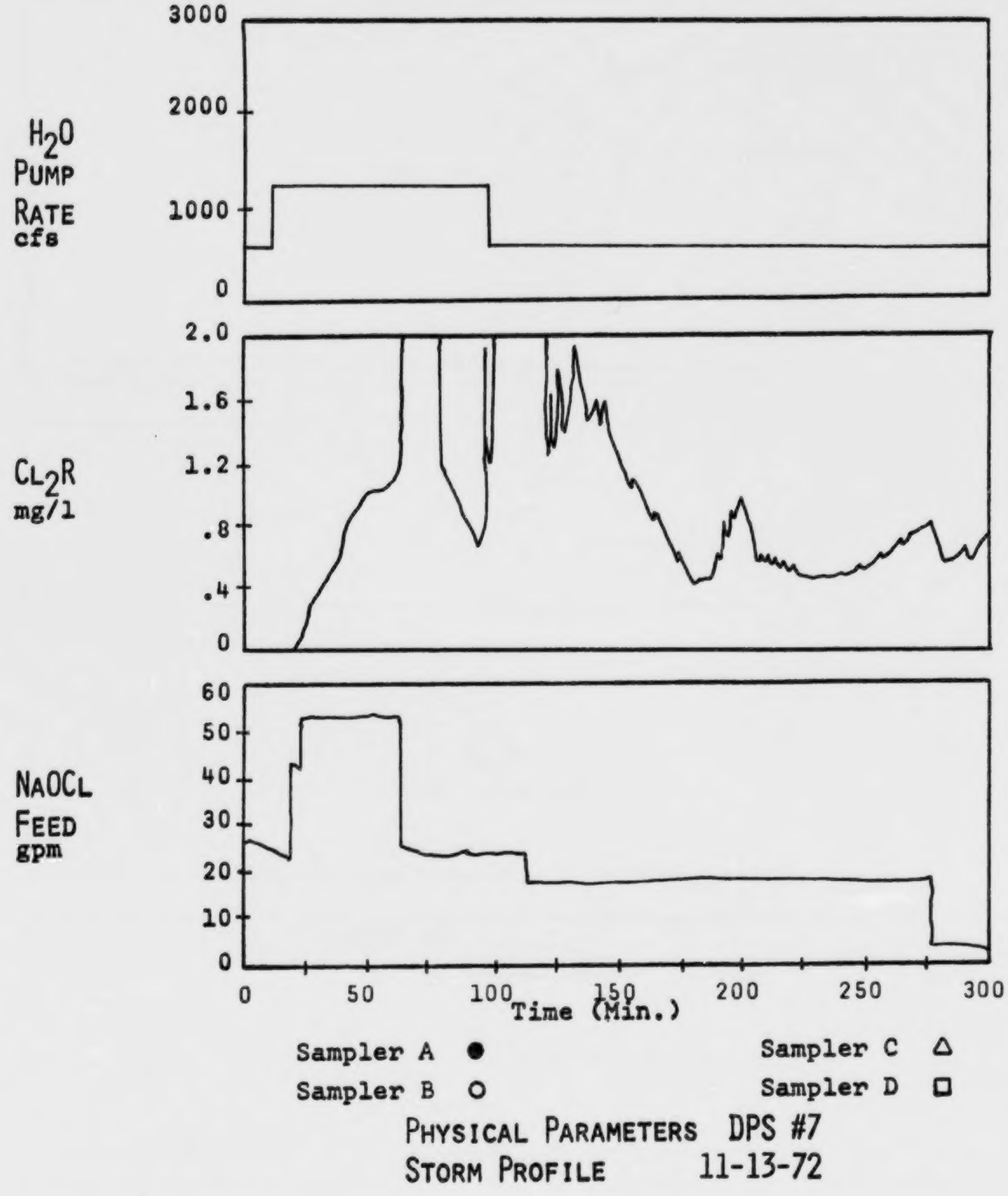


Figure 47. DPS #7 - STORM PROFILE PHYSICAL RESULTS NOV. 13, 1972

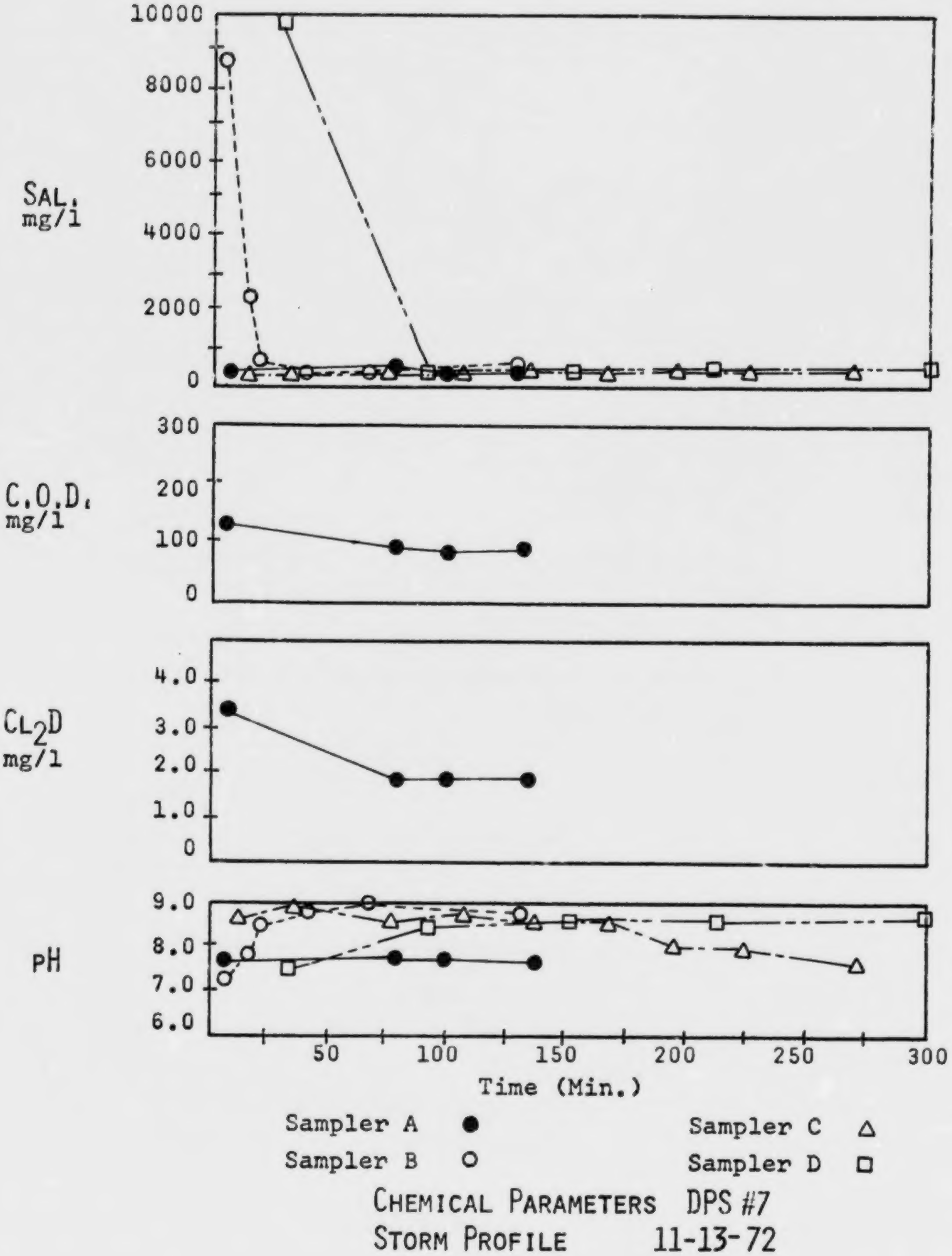


FIGURE 48. STORM PROFILE CHEMICAL RESULTS NOV. 13, 1972

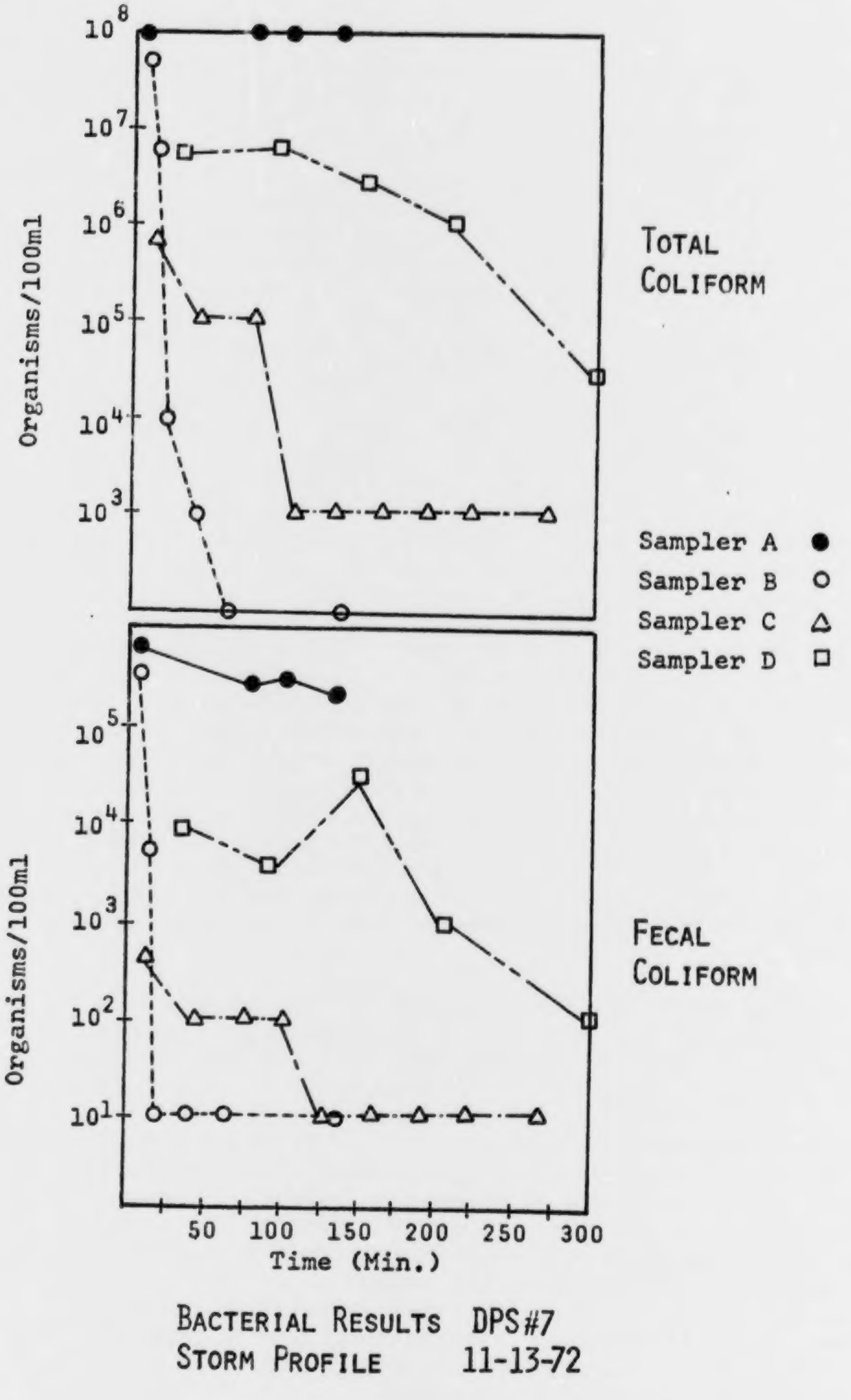


FIGURE 49. DPS #7 STORM PROFILE BACTERIAL RESULTS NOV. 13, 1972

attempts of the operator to maintain the residual between 0.5 and 2.0 mg/l are evident. The initial NaOCl feed rate was 22 - 25 gpm. This feed rate is usually sufficient to maintain this residual level with storm water pumping at 550 cfs if the chlorine demand approximates 3.5 mg/l. However, the initial feed rate required depends on the instantaneous strength of the NaOCl stored at the station. During this storm the initial NaOCl feed rate was not adequate, but since there is approximately a 20 min transport delay, τ_{ab} = 20 min, the operator is not aware of this initially. The doubling of the NaOCl feed rate to 44 gpm at the 20 min mark was due to an increase in the pumping rate. Finally at t = 24 min, the operator has the first indication that he is not in the desired residual range. The operator then increases the NaOCl feed rate to 53 gpm and maintains it until t = 60 min. At this time the residual rises above the 2.0 mg/l range of the chart. The NaOCl feed rate is then decreased to 22 gpm. It can be noted that the residual does not begin to drop until t = 80 min. The man-residual feedback loop is obviously very unstable. The operator maintains the NaOCl feed rate at 22 gpm but the pumpage rate is decreased to 550 cfs at t = 95 min. The residual again rises and the operator decreases the feed rate 18 gpm which is maintained until the cessation of disinfection. The fluctuation of chlorine residual due to changes in demand during the latter stages, and pumpage rate throughout the storm profile is clearly seen. From Figure 48 it can be seen that the chlorine demand is higher initially and thus requires a greater NaOCl feed level to effect a residual. At t = 75 min the demand drops and the composite average remains constant at 1.9 mg/l. Compositing of the samples obscures the minor fluctuations in the demand seen at the end of the treatment period.

The bacterial results of the treatment are plotted in Figure 49. As expected, influent coliform levels at A are very high with total coliforms exceeding 10^7 org/100ml while fecal coliforms exceed 10^5 org/100ml. At B, the initial levels are comparable. A note of explanation is usefull here. The initial coliform levels at B, C, D in the outfall canals should be nearly equal and approximately two orders of magnitude lower then the suction bay levels. However, the location of B, in the discharge bay, causes the initial B samples to approximate the conditions in the suction bay almost immediately when pumping starts. In fact, due to stirring up of the benthos, initial conditions at B are sometimes worse than at A. Occasionally, the samplers are turned on prior to initiation of pumping and then the B, C, and D values are comparable (App3-2). Once treated water reaches B, we see a rapid decline in the coliform levels to less than 10^1 org/100ml. The uncertainty arises since the plate counts were zero for this and higher dilutions. Moving to C, we see that the initial total coliform value is $\sim 10^5$ org/100 ml which holds until t = 45 min. The values then drop to 10^4 org/100ml as the first treated water reaches C. A second drop to $<10^2$ org/100ml comes to t = 100 min as the main wave front passes. The transport delay τ_{bd} is in the order of 200 min since the total coliform values at D remain steady until this time. It is interesting to note the broadening of the bacterial decrease "wave" as it proceeds down the outfall canal.

The characteristics of the wave front can also be seen in the salinity levels. As the front passes B, C, and D the salinity levels decrease from the normal lake levels, 3,000 to 10,000 mg/l to those found at A in the suction bay, 100 to 500 mg/l. Although there are differences in the delay time, the reasons for these are not clear.

The initial "flushing" of the drainage system can be seen in the decrease of the COD and Cl_2D levels as time passes. Also, the solids levels decreased with time. Figure 50 shows the average over sixteen storm profiles of total suspended matter levels taken on initial and final composite samples. The roiling effect of pumping from A to B is evident in the initially high levels at B. Finally, it is interesting to note that the addition of NaOCl substantially raised the pH at B. This is due to the hydrolysis of NaOCl to HOCl and NaOh. Obviously, the latter will increase the pH considerably. This is of concern since the resulting equilibrium of HOCl with H^+ and OCl^- is unfavorable affected. However, elevated pH levels did not appear to interfere with coliform reductions during the profile.

Although there were some minor variations these results were typical of the sixteen storm profiles run. Table 18 contains a comparison of the maximum coliform density reductions and chlorine residuals for the various storm profiles. Point D is not included since during several storms treated water did not reach it or the minimum bacterial value was not attained. The values of chlorine residuals for the B samples were attained by sampling the chlorine residual data record in the same manner that the B sampler had taken the storm water samples, i.e., to attain a chlorine residual for composite sample 1, 2 at B the chlorine residual values at four minutes and eight minutes on the strip chart recording were averaged. It was assumed that the minimum coliform value at C represented the same treated storm water which resulted in the minimum value at B. It is evident from Tables 10 and 18 that higher residuals

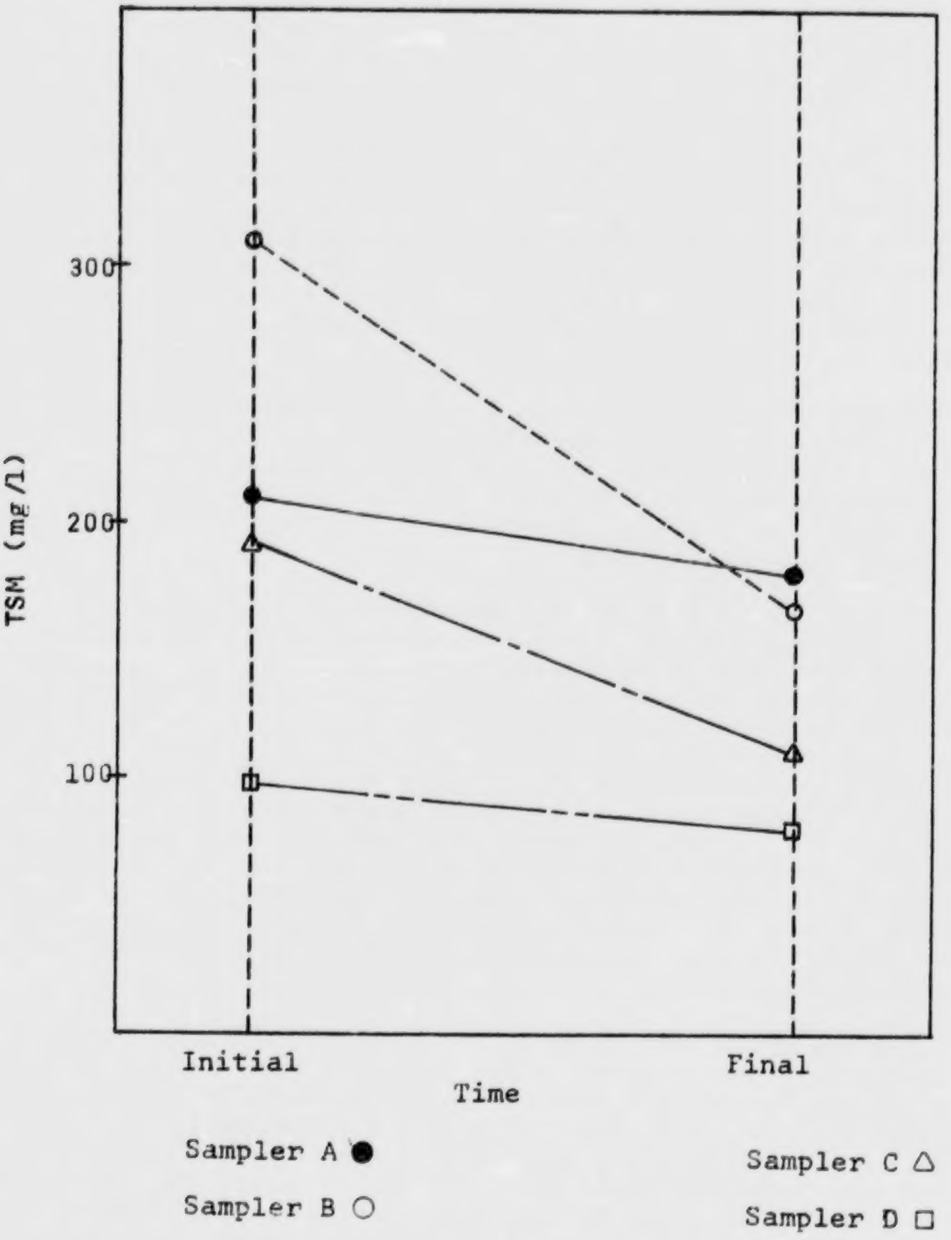


FIGURE 50. DPS #7 - POST-CONSTRUCTION EVALUATION PROGRAM AVERAGE TOTAL SUSPENDED MATTER INITIAL & FINAL SAMPLES

TABLE 18

DPS #7 - MAXIMUM COLIFORM REDUCTION FOR SIXTEEN STORM PROFILES

Date	ClR - B min. mg/l	TC Values A	TC Values B min.	TC Values C min.	Mag. Red. - TC B/A	Mag. Red. - TC C/A	Mag. Red. - TC C/B	FC Values A	FC Values B min.	FC Values C min.	Mag. Red. - PC B/A	Mag. Red. - PC C/A	Mag. Red. - PC C/B
12/7/71	**	10^7	10^5	--	10^2	--	--	10^4	10^2	--	10^2	--	--
2/7/72	**	10^7	10^4	10^3	10^3	10^4	10^1	10^4	10^2	10^1	10^2	10^3	10^1
3/2/72	**	10^7	10^5	10^5	10^2	10^2	--	10^8	10^1	10^1	10^7	10^7	--
3/9/72	**	10^7	10^4	10^4	10^3	10^3	--	10^4	10^2	10^2	10^2	10^2	--
3/19/72	**	10^7	10^4	10^3	10^3	10^4	10^1	10^5	10^2	10^1	10^3	10^4	10^1
5/11/72	.35	10^6	10^4	10^3	10^2	10^3	10^1	10^4	10^2	10^1	10^2	10^3	10^1
5/12/72	.52	--	10^3	10^3	--	--	--	--	10^1	10^1	--	--	--
6/9/72	.22	10^7	10^5	10^4	10^2	10^3	10^1	10^5	10^3	10^2	10^2	10^3	10^1
7/5/72	.45	10^6	10^3	10^3	10^3	10^3	--	10^6	10^1	10^1	10^5	10^5	--
7/12/72	.56	10^7	10^3	10^3	10^4	10^4	--	10^4	10^1	10^1	10^3	10^3	--
7/13/72	.28	10^6	10^3	10^3	10^3	10^3	--	10^4	10^1	10^1	10^3	10^3	--
7/20/72	1.40	10^7	10^2	10^2	10^5	10^5	--	10^5	10^1	10^1	10^4	10^4	--
9/30/72	1.26	10^7	10^3	10^2	10^4	10^5	10^1	--	--	--	--	--	--
10/22/72	.45	10^7	10^3	10^3	10^4	10^4	--	10^5	10^1	10^1	10^4	10^4	--
11/4/72	.35	10^7	10^2	10^3	10^5	10^4	--	10^5	10^1	10^2	10^4	10^3	--
11/13/72	2.00	10^7	10^1	10^2	10^6	10^5	--	10^5	10^1	10^1	10^4	10^4	--

** Not Available

result in higher levels of coliform reduction. The effect of the increased contact time is also seen occasionally. The occurrence is not uniform since little effect will be demonstrated at high dosage levels. At the lower residual levels mixing with untreated water may occur between B and C when channeling is present and result in higher bacterial levels at C. However, the effect of contact time can be used to advantage by treating the water at lower residual levels, i.e., 0.5 mg/l.

The chlorine residual analyzers utilized during this project measured total available chlorine. Thus, free and combined chlorine could not be separated. However, increased levels of kill were found with increased residuals. From a consideration of the strom profiles, chlorine residuals greater than 0.5 mg/l resulted in 99.99% or greater reduction of bacterial densities. The effects of contact time could be seen when bacterial levels at C were consistently lower than comparable levels at B. Unfortunately, it was not possible to ascertain statistically the relative importance of each factor in the treatment process due to a lack of point A samples. The sampler inlet at A (Figure 51) was located at the entrance of the feeder canal into the suction bay.

Reproduced from best available copy.

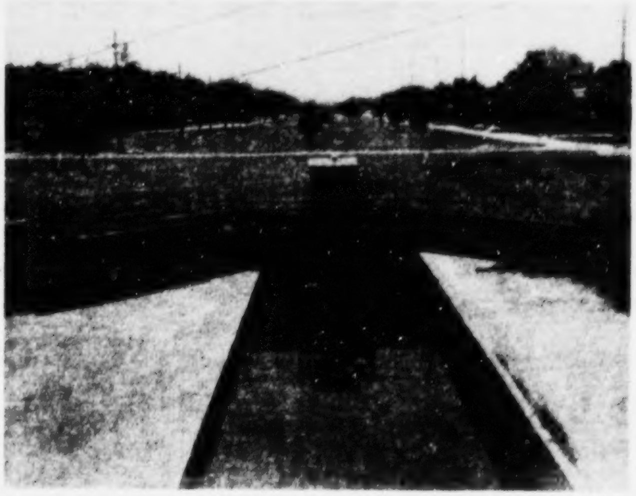


Figure 51 - Point A - Sampler Inlet at DPS #7

No problems were encountered at low flow rates, but during high flow rates the sample head would tilt breaking prime on the sample pump and no further samples could be taken. During one very high flow rate the sampler head was dislodged entirely. An attempt was made to move the sampler inlet to a protected area to the side of the feeder canal, but this was unsatisfactory since the samples taken no longer represented the influent conditions. A complete redesign of this sampler inlet would be required if further studies are to be performed. However, on the basis of storms where A values were available, it could be seen that only a slight decline in initial coliform levels occurred (App. 1-2).

The main objective of the project was to decrease the total and fecal coliform levels in the storm water which subsequently reached Lake Pontchartrain by means of the outfall canals. By analyzing the results of individual storm profiles, this goal appeared to be well in hand. Except for a pre-residual period at the initiation of pumping, coliform levels for most of the storm water pumped were decreased by four or more orders of magnitude (>99.99%) to levels below 1000 org/100ml. However, when storm profiles were taken on May 11 and 12, 1972 and July 12 and 13, 1972 (App. 6, 7, 10 & 11) it was noticed that total and fecal coliform levels which had been reduced to 10^3 org/100ml and 10^1 org/100ml, respectively, had recovered to levels normally present in the canals (10^6 org/100ml, 10^5 org/100ml). At first it was thought that the levels at B and C were being increased by lake water entering the outfall canals. However, salinity levels at B and C on the second day had not recovered to their normal levels and were at the same level as when pumping had ceased on the previous day. This is shown by comparing App. 6-2 and 7-2 where salinity levels for May 11, 1972 and May 12, 1972 are plotted.

On May 11, 1972, the normal increase in salinity levels as one proceeds downstream toward the lake is present. Once pumping begins, the salinity levels drop as the treated, low salinity water from A reaches B and C. As can be seen, no treated water reaches D. On May 12, the original salinity levels at B, C, and D are all very low. Evidently, the treated water diffused to D in the twenty-four hour period between pumping episodes. Thus, the coliforms appeared to regrow rather than being imported from the lake by tidal action.

To explore this behavior further, an aftergrowth study was initiated at C. So that the course of bacterial regrowth in the natural environment of the outfall canal could be determined, sampler C was utilized to take samples at two hour intervals for thirty hours after cessation of pumping and disinfection. The samples were then analyzed and coliform, pH,

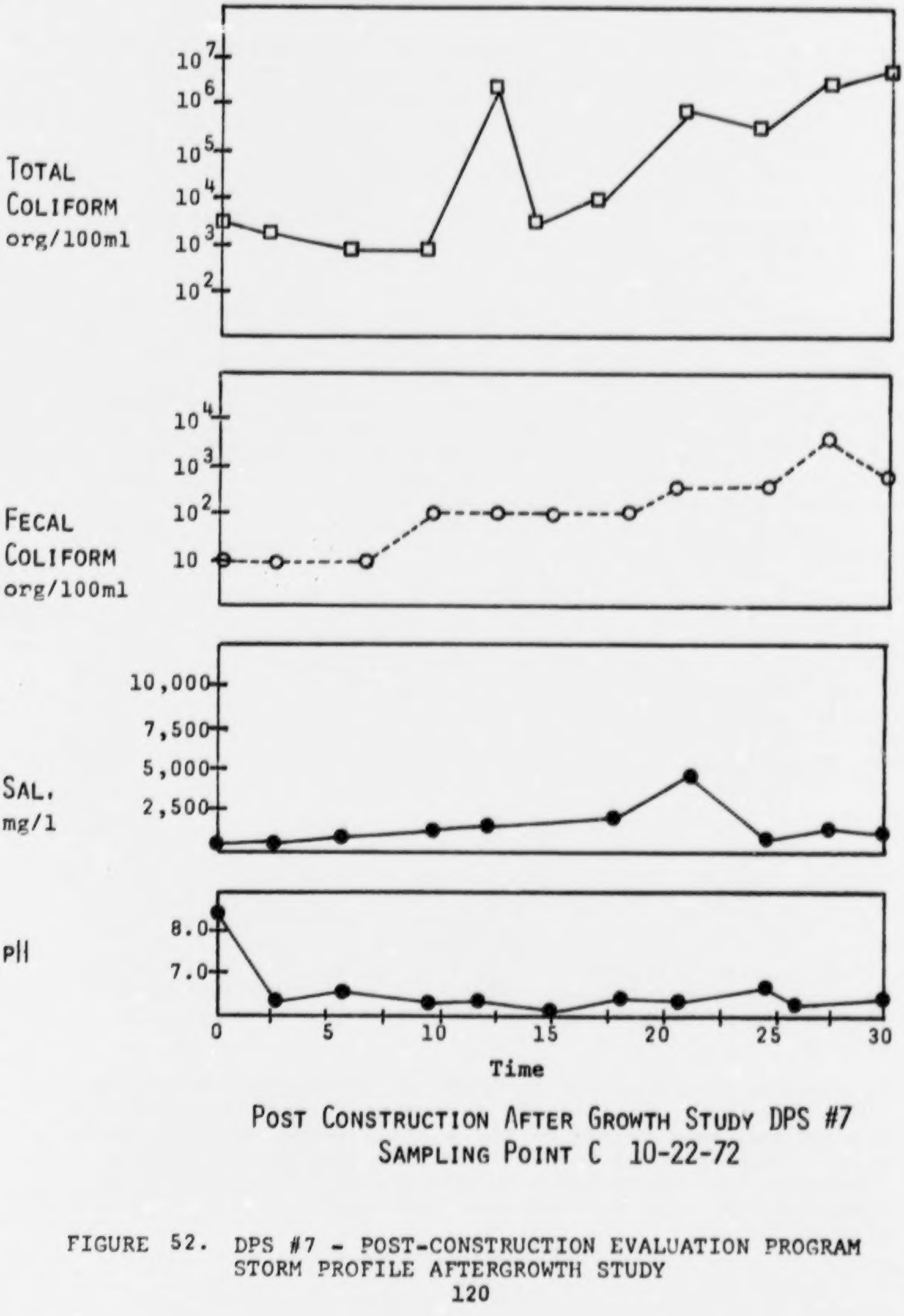


FIGURE 52. DPS #7 - POST-CONSTRUCTION EVALUATION PROGRAM STORM PROFILE AFTERGROWTH STUDY

and salinity levels were determined. The results are shown in Figure 52. The original dip in the curve is probably due to dieoff of organisms which began after contact with NaOCl. This effect ceases after six hours and there is a uniform, possibly logarithmic, regrowth of total and fecal coliform organisms. It is believed that the reading at τ = 12 hr is an analytical error since no concurrent increase in fecal coliform is noted. Total coliforms increased to 10^6 org/100ml which approximates the normal level in the Orleans Avenue canal. Significantly, the fecal coliforms only recovered to 10^3 org/100ml. This level is approximately two orders of magnitude less than was ordinarily present in the Orleans Avenue canal. This could explain the long term decrease in the fecal coliform levels observed in the routine data.

Although additional aftergrowth studies with better controls would have to be carried out to substantiate these observations, the regrowth phenomenon is a well known microbiological event. In order to clarify the implications of coliform regrowth with respect to the goals of the project, the microbiological aspects of disinfecting bacterially polluted storm water had to be considered.

SECTION X

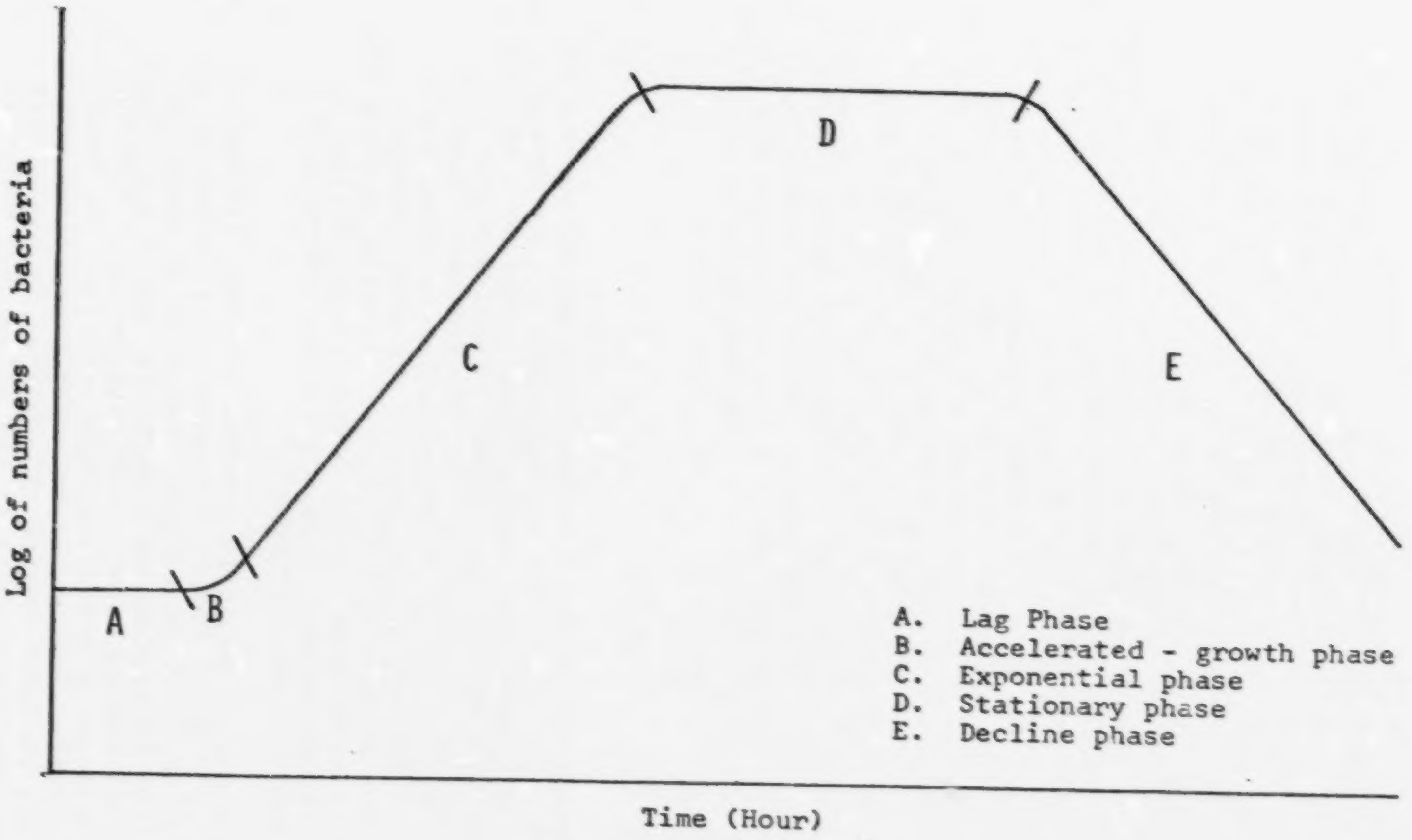
MICROBIOLOGICAL ASPECTS OF STORM WATER AND DISINFECTION

GROWTH

In order to explain certain observations made during the Pre-Construction and Post-Construction Evaluation Programs, it is necessary to refer to the microbiological aspects of disinfection of storm water (7, 8). If storm water is disinfected through use of NaOCl (or any disinfectant) the number of coliforms, pathogens, etc, in the storm water is reduced to a very low level. If this small number of microorganisms is considered analogous to a mass of organisms in a bacteriological culture medium, the growth curve, under favorable conditions, would look like Figure 53.

The growth of the microorganisms has several phases. Logarithmic growth starts a short time after the residual chlorine level falls to zero and the remaining microorganisms come into contact with the nutrients in the storm water. In the logarithmic growth phase there is always an excess of food around the microorganisms. The rate of metabolism and growth is limited, in this case, only by their ability to process the nutrients in the polluted storm water. At the end of the logarithmic phase the microorganisms are growing at the maximum rate. At the same time they are removing organic matter from the water at their maximum rate. Needless to say the limitations of food causes the rate of growth to decrease in the declining growth phase. As the microorganisms lower the nutrient concentration, the rate of growth decreases. When growth ceases, the nutrient concentration for the species is at a minimum and the organic matter still in the waste water is in equilibrium with the number of microorganisms. For coliform bacteria the time base for the log growth and the declining growth phases is approximately 24 hours. Following the declining growth phase, the number of microorganisms remains constant during the stationary phase. Once the nutrient levels are lowered below the critical level die off begins.

The growth pattern of microbial organisms can explain several observations of the Pre and Post-Construction Evaluation Programs. During the pre-construction program, a gradual die off of bacteria in the outfall canals was noted with time after pumping. It can be seen that the bacteria originally



BACTERIAL GROWTH CURVE

FIGURE 53. BACTERIAL GROWTH CURVE

present in the water rapidly enter the stationary and die off phase of growth with its gradual decrease in the number of microorganisms. This accounts for the decrease in bacterial levels noted during the Pre-Construction Evaluation Program. In the Post-Construction Evaluation Program, disinfection with NaOCl decreased the total number of organisms in the water to very low levels while having only a negligible effect, from the microbial view, on the amount of organic material present as nutrient substrate. Thus, the coliform bacteria surviving disinfection are in the logarithmic growth phase and the declining growth phase for the first 24 to 30 hours. This results in a rapid recovery of the bacterial population to that level normally found in the outfall canal. This rapid recovery, once the residual chlorine level has dropped to zero, casts serious doubt on the ability of the project to attain its goal of reducing the coliform bacteria count in the water discharged into the surrounding recreational areas. It was apparent that unless a residual chlorine level is kept in the water in the outfall canal at all times, a rapid recovery of indicator bacteria takes place. Since there are over 10,000,000 cu ft of water and associated benthos in most of the outfall canals, it is not economically possible or ecologically desirable to keep a chlorine residual in the outfall canal at all times. This led to a reevaluation of the goals of the project.

Origin of Pathogens

The primary reason for treating water is to remove human specific pathogens from it. Thus, disease will not be caused in humans when polluted water subsequently comes into contact either with the skin or enteric system. Human specific pathogens are normally transmitted to water by pollution of fecal origin. The access of fecal pollution to water may add a variety of intestinal pathogens. The most common pathogens include strains of *Salmonella, Shigella, Leptospira,* enteropathogenic *Escherichia coli, Pasteurella, Vibrio, Mycobacterium,* human enteric viruses, cysts of *Endamoeba histolytica,* and hookworm larvae.

These pathogens may be found in sewage, streams, irrigation waters, wells, and tidal waters. However, the isolation of pathogens from the water environment has been infrequently performed because laboratory methods of isolation and identification remain too cumbersome for routine use. For this reason, the presence of total and fecal coliform has been used as an indication that other pathogenic organisms may be present. The rational behind this method is that total and fecal coliforms are present in the alimentary tract of humans, as are pathogens when the host is infected.

Originally indicator bacterial tests included the coliform group as a whole. However, Eiijkman (9) introduced a modification which distinguished between soil based coliform and enteric coliforms. In this modification, those coliform which are found in the alimentary tract of warm blooded animals and capable of growth at the normally inhabiting temperature of 44.5°C are operationally defined as fecal coliforms. Since both soil based and enteric coliforms could multiply at 37°C this combination was designated as the total coliform group. The monitoring of sewage for pathogens using total and fecal coliform indicators has been demonstrated to be an excellent epidemiological tool for monitoring water borne diseases that may be prevalent in the community at the moment. However, it must be remembered that this observation has its greatest utility when the fecal material is known to be of human origin.

While the microbial discharge of warm blooded animals is usually not harmful to humans, pathogens may be found in the intestinal tract of warm blooded animals. These sources include animal pets (10), livestock (11). poultry (12), and the wild animal community (13). The animals come into contact with human specific pathogens through contaminated food and water sources (14) and may themselves come infected or serve as carriers. Among the cold blooded animals, fresh water fish and turtles may harbor human pathogens after exposure to contaminated water or food sources and carry these organisms to recreational areas (15). This occurrence of pathogens in domestic animals and wildlife illustrates the concern about fecal pollution from all warm blooded animals and not just from man. However, it must be remembered that the human specific pathogen may loose its pathogenicity when passing through any link of the chain; infected host, fecal pollution, nonhuman or water host, exposed humans.

In the present project, the effect of environment once the human specific pathogen leaves its host is of the utmost importance. In most cases the path traveled by a hypothetical pathogen will be a cross connection between the sanitary and storm sewerage systems for human pathogen sources and storm water runoff for animal borne pathogens. The possibly contaminated storm water is collected by the drainage system and pumped into the outfall canals. Once in the outfall canals, the storm water can subsequently reach recreational areas where humans may be exposed if any pathogens are present. Thus, it is necessary to investigate the survivability of pathogens in the storm water once they leave the host organism.

Effect of Environment on Pathogen Survival

The survival of *Salmonellae* in the aquatic environment is influenced by the same factors that control the persistence of fecal pollution indicators. Nutrient rich waste, lower stream temperatures, cold blooded host, and a source of *Salmonellae* can produce an impact downstream. However in several studies (16), *Salmonellae* were added to individual storm runoff samples and stored either at 10°C or 20°C to approximate the water temperature in the environment. Results showed a 99% attrition of *Salmonellae* in the storm water samples held ten days at 20°C while 5% of the bacteria persisted beyond 14 days in runoff water stored at 10°C. However, in no instance did *Salmonellae* levels increase in the storm water samples.

Another water borne pathogen causes leptospirosis. This disease is due to a group of coil-shaped, actively motile bacteria, *Leptospirae*. These pathogens gain access to the blood stream through skin abrasions or mucous membranes and cause lesions involving the kidneys, liver, and central nervous system. Although leptospires from infected reservoir hosts may be present throughout the year, infections in the United States are most frequent during the recreational season (21). Again several variables affect the survival of leptospires in the storm water environment. At low temperatures multiplication of these organisms is retarded, but persistence is increased over that for summer temperature levels.

A commonly identified cause of intestinal disease in the United States is exposure to *Shigella*. This may occur from person to person contact and contaminated drinking water or food. The survival of shigella strains once they enter the water environment is limited by many ecological factors. As observed with *Leptospira* and enteric viruses, persistence of *Shigella* in water is much better when the total bacterial population is low (17, 18). Most interesting is the negative reaction to formic and acetic acids produced by coliform organisms. The coliform group acid production apparently has a bacteriostatic to bacteriocidal effect on the *Shigella* strain (19). A second important factor is water pH. Experiments on survival and recovery of *S. flexmeri* in the intestinal tract of carp and bluegill indicated regrowth when incubated at 20°C in a 1% fecal suspension which was free of coliform and had a pH of 7.6 to 8.3. However, several experiments in 1% fecal suspensions and an initial pH of 7.2 showed a rapid die off of *Shigella* within several days (20). Water temperature also influences the levels of *Shigella*. That is, it survives longer at lower temperatures as do all other bacteria.

The salinity level of the environment also influences the survival of leptospires. The organisms can survive more than 10 days in lake water of low salinity. In lake and river waters with moderate salinity levels (70 - 7000 mg/l chloride), leptospires survived for less than one week. In sea water with a salinity of 13,000 to 17,000 mg/l chloride, survival time was reduced to less than one day (22). Another factor that influences leptospire persistence in the water environment is the density and composition of the microbial population. Leptospires are inhibited rapidly when mixed with fecal material at either 5°C or 37°C (23). Also, raw sewage with its varied microbial population shortens survival to 12 to 14 hours (24).

Serious intestinal disease in young children is often due to infection by enteropathogenic *E. coli*. *E. coli* generates an enteric disease characterized by profuse watery diarrhea, nausea, and dehydration with a general absence of fever. A causal relationship of *E. coli* in humans due to exposure to animals has yet to be established. When *E. coli* is found in fresh or brackish water, its occurrence indicates a recent introduction of fecal contamination. Multiplication of *E. coli* is observed in untreated cannery waste, poultry processing waste, and raw domestic sewage. These discharges can all be characterized as having warm temperatures and large quantities of bacterial nutrients. After dilution by better quality water downstream or exposure to waters with high salinity levels, multiplication of *E. coli* is suppressed (25, 26). Thus, environmental forces can produce a sharp die off of *E. coli* purification with only 10% viable organisms present after two to five days has been found (27).

One other important observation has been the persistence of *Vibrio cholerae* in some polluted aquatic environments, although the organisms should persist only a short time. This contradictory behavior was noticed in persistence of *V. cholerae* from the Hoogly River in Calcutta, India (28). Even after chlorination (2.0 to 3.0 mg/l, ten minute contact time) cholerae, vibrios, and salmonella are found (29). It is probable that pathogenic bacteria present in the poor quality water are protected in clumps of particles from exposure to the chlorine during the disinfection period. Thus, there is a persistence of pathogenic bacteria in very turbid waters.

Application to Outfall Canals

In the urban community, fecal contamination in separate storm water runoff is derived from the fecal material deposited on soil by dogs, cats, and rodents or sewage cross connection. Survival of human specific pathogens in the water environment is influenced by many of the ecological forces previously discussed. These factors need to be taken into consideration in elucidating the fate of pathogenic organisms in the aquatic environment. The main factors are:

1. Temperature.
2. Interference of growth due to competing microorganisms in the water.
3. Time since introduction of microorganisms into water.
4. The effect of substances such as NaOCl or other inhibitory chemicals either from natural or a man-made source.
5. The presence of solid material in the water which can shelter the microorganisms from attack.

For the particular treatment situation in the outfall canals, the conditions are such that it is very unlikely that pathogens could survive in any great number once disinfection has occurred. Temperature in the outfall canals ranges from 60°F to 85°F and thus, does not greatly enhance the survivability of the organisms. Additionally, the solids level of the storm water is low so that the number of enclosed organisms should also be low. Also, the receiving stream has a moderate level of salinity and thus organisms affected by increased osmotic pressures should not fare well. Bacteriological studies are indicated to confirm these conclusions for pathogens in storm water. However, the fact that the environment in the discharged storm water is not conducive to regrowth of fecal organisms was demonstrated by the results of the long term routine sampling, storm operation aftergrowth studies and the storm profile aftergrowth study. Also, it should be noted that the levels of indicator bacteria in the outfall canals after disinfection and regrowth no longer provide the same measure of possible pathogenicity of the storm water unless new sources of pollution are present.

Effluent Criteria

There is no doubt that the use of coliform groups as indicators of contamination has been an extremely useful epidemiological tool. However, once storm water has been disinfected, the significance of the coliform group should be reevaluated since the alternatives of continued chemical treatment or solids removal are extremly costly. In addition, there are only three possible spheres of disposal which can ultimately be used; air, water, and land. The transfer of the problem from one sphere to another occurs only at the cost of additional expenditures of energy and, thus, more pollution. For the particular case of large volumes of bacterially polluted storm drainage water, it might be best to allow natural processes to remove the nutrients if the original treatment with disinfectant is adequate from health standpoints and the subsequent environmental factors are not conducive to pathogen regrowth even if coliform levels recover. Additional study is needed to provide simple tests for pathogen detection and to determine the effects of disinfection and subsequent environmental factors on pathogens.

SECTION XI

ECONOMICS

GENERAL

The addition of NaOCl to polluted storm water involves eight major cost elements; amortization, land, manufacturing facilities, transportation facilities, storage facilities, chemical feed systems, chemicals, and operation and maintenance. The first six are fixed investment costs while the last two are dependent on the amount of storm water pumped and the degree of treatment required. Sales taxes on equipment and freight charges were not included in the calculations since they vary substantially with location of the facilities. The cost of construction of the reaction basin at St Charles was also neglected.

MANUFACTURING FACILITIES

The NaOCl manufacturing plant developed for this project was of a novel design, subsequently patented, which can continuously manufacture high strength NaOCl under atmospheric conditions. As is usual in process development, the design and construction costs were higher than one would normally expect for a facility with which a great deal of experience had been available. For this reason, design costs are not included in the cost of construction of the plant. The fixed costs of the various facilities at the manufacturing plant are shown in Table 19. Table 20 shows the cost of manufacturing 1,000 gal. of 120 gpl NaOCl from the basic chemicals which are delivered to and stored at the plant. The sums shown are the average costs encountered during the project for producing the NaOCl. As can be seen,the price $78.52/1,000 gal. of 120 gpl NaOCl is comparable with commercially available NaOCl at a much lower solution strength. It should be noted that the water used for manufacturing and cooling of NaOCl is provided at wholesale by the Sewerage and Water Board of New Orleans. The cost for the water is only $.035/1,000 gal., and was neglected.

FEEDING FACILITIES

The fixed costs of the feeding facilities at each pumping station is shown in Table 21. The differences in the price of the storage tanks at the various stations is due to differences in

Reproduced from best available copy.

TABLE 19

FIXED COSTS : NaOCl MANUFACTURING PLANT

A. Equipment	Item	Cost
	H_2O Pumps	$ 2,100.00
	Refrigeration Equipment	13,931.00
	2 NaOCl Pumps	2,994.75
	Heat Exchanger	2,975.00
	NaOH Storage Tank	19,290.00
	2 NaOCl Storage Tanks	19,208.00
	NaOCl Averaging Tanks	201.96
	Chilled Water Pumps	950.25
	Miscellaneous	11,496.73
		$ 73,147.69
B. Construction		181,733.70
C. Supervision		27,516.75
	TOTAL	$282.398.14

TABLE 20

AVERAGE COST OF MANUFACTURING NaOCl (1,000 gals. of 120 gpl NaOCl)

ITEM	COST
Electricity	$ 2.09
Labor	11.66
Chlorine	16.30
Sodium Hydroxide	47.47
Maintenance	1.00
TOTAL	78.52

TABLE 21

FIXED COSTS: NaOCl FEEDING FACILITIES

ITEM	DPS #3	DPS #4	DPS #7	ST CHARLES
(2) NaOCl Storage Tanks	$19,208.00	$20,075.00	$24,453.00	$20,075.00
(2) NaOCl Pumps	1,593.83	1,593.83	1,593.00	1,593.83
Misc. Equip. and Construction	47,279.04	45,353.00	57,186.00	33,700.48
Supervision	6,879.18	6,879.18	6,879.18	6,879.18
Sub Total	$74,960.05	$73,901.01	$90,112.01	$62,248.49

TOTAL COST: $301,221.56

TABLE 22

FIXED COSTS: CHEMICAL FEED SYSTEMS

ITEM	DPS #3	DPS #4	DPS #7	ST CHARLES
Cl_2R Analyzers	$ 1968.75	$ 1968.75	$ 1968.75	$ 1968.75
Electronic Equipment	4904.33	4904.33	5121.00	4904.33
Water Samplers	——	2724.88	10899.52	5449.76
DO Analyzers	1166.25	1166.25	1166.25	1166.25
Construction	7511.89	7511.89	7511.89	7511.89
Sub Total	$15,551.22	$18,551.22	$26,667.41	$21,000.98

TOTAL COST: $ 81,495.71

TABLE 23

TOTAL FIXED COSTS

NaOCl Manufacturing Facilities	$ 282,398.14
Transportation Costs	35,960.04
NaOCl Feeding Facilities	301,221.56
Chemical Control Facilities	86,945.47
TOTAL COST	$ 706,525.21

the linings. The different physical characteristics of pumping stations altered the construction costs. The increased cost of the electronic equipment at DPS #7 is due to the fact that it was ordered one year after the other electronic equipment. The prototype sampler used at DPS #3 was built by the Sewerage and Water Board machine shop at the initiation of the project and its cost was not included.

TRANSPORTATION FACILITIES

The cost of the two NaOCl transport trucks was $35,960.04. The operation and maintenance cost of the trucks will vary with the frequency and degree of treatment required, and is neglected.

CHEMICAL FEED SYSTEMS

The cost of NaOCl feed and control systems at the various stations is shown in Table 22. The figures here might increase somewhat in subsequent facilities since a change in the type of feed pumps or regular replacement of pumps is indicated (pg). However, if provision is made to completely flush the pumps during the periods between operation, these pumps might be used for the life of the manufacturing plant.

SUMMARY

The total fixed costs of hypochlorination are given in Table 23. Assuming a total life of 10 years for the facilities, and an interest rate of 6%, the fixed costs are $53,600/yr.

The calculation of disinfection cost will be based on treating storm water with a chlorine demand of 3.5 mg/l so as to maintain a 1.0 mg/l residual at all times. This requires a dosage rate of 4.5 mg/l (4.5 g/264.2 gal.). A conservative estimate of the average decrease in strength of the NaOCl in the field was 4 g/l/wk. Assuming eight weeks storage before ultimate use, 1,000 gal. of 120 gpl NaOCl manufactured at the plant can ultimately treat 19,600,000 gal. of storm drainage water.

The average yearly pumpage of the four pumping stations in the project is approximately 5×10^{10} gal. if all pumpages are considered. The yearly fixed costs are $53,600 and the manufacturing cost of the NaOCl required to disinfect 5×10^{10} gal. of storm water is $200,300. On this basis, the average yearly cost of treatment would be $.000051/gal. of storm water.

SECTION XII

ACKNOWLEDGEMENTS

Sewerage and Water Board of New Orleans

The support of Mr. E.F. Hughes, General Superintendent (Ret.), Mr. G. Joseph Sullivan, General Superintendent, and Mr. D.D. Modianos, Assistant General Superintendent, is acknowledged with sincere thanks.

Mr. Crawford J. Powell, Assistant General Superintendent (Ret.) made the original suggestion for the project and gave counsel and support through the construction and early operational phases.

Mr. Ray A. Beaman, Clark L. Fox, and Anthony H. Carver gathered water samples, ran chemical analyses, and maintained the storm water sampling equipment.

Mr. George Hopkins, Water Treatment Superintendent, and Mr. William F. Wells, Water Chemist, directed and supervised the sodium hypochlorite manufacturing facilities.

Mr. Louis Meridier and Mr. E.H. Arnold provided mechanical and electrical maintenance support for the project.

Pavia-Byrne Engineering Corporation

Mr. Gerard S. Pabst, Jr. consulted on the microbiological aspects of the project.

Sincere thanks are extended to Mrs. Joan Herzog, Miss Susan Luttmann, and Miss Linda Herzog for their patience and diligence in typing the final report.

Environmental Protection Agency

The help and support of Mr. Robert Hiller, Project Officer, is acknowledged with sincere thanks.

The guidance and encouragement of Mr. Frank Condon, Headquarters Staff Office of Research and Monitoring, Washington, D.C., and Mr. George Putnicki, Director of Surveillance and Analysis Division, Region 6, was greatly appreciated.

SECTION XIII

REFERENCES

1. Pavia, E. H., and C. J. Powell, "Storm Water Disinfection at New Orleans", JWPCF, 41:1, 591 (1969).

2. Geldrich, E. E., L. C. Best, B. A. Kenner, and D. J. Van Donsel, "The Bacterial Aspects of Storm Water Pollution", JWPCF, 40:1 1861 (1968).

3. Kendall, M. C., and A. Stuart, The Advanced Theory of Statistics, Griffen, London, 1966.

4. Biguria, G., R. C. Ahlert, and M. Schlanger, "Distributed Parameter Model of Thermal Effects in Rivers", 1969 Stream Pollution Abatement Conference, Rutgers University, 1969.

5. Dresnick, R., and W. E. Dubbins, "Numberical Analysis of BOD and DO Profiles", J. Sanit. Engr. Div. : Proc. ASCE, 94;SA5, 789 (1968).

6. Verhoff, F. H., W. F. Echelberger, Jr., M. W. Tenney, and P. C. Singer, "Lake Water Quality Predictions Through Systems Modeling", 1971 Summer Computer Simulation Conference, Boston, 1971.

7. Geldreich, E. E., "Water Borne Pathogens", Water Pollution Microbiology, edited by Ralph Mitchell, John Wiley and Sons, Inc., 237 (1972).

8. Pelczar, Jr., M. J., and R. D. Reid, Microbiology, McGraw-Hill Book Company, New York, 1958.

9. Eiijkman, C., "Die Garungsprobe bei 46°C als Hilfsmittel bei der Trinkwasseruntersuchung", Centr. Bakt., 37,742 (1904).

10. Galton, M. M., J. E. Seatherday, and A. V. Hardy, "Salmonellosis in Dogs", J. Infec. Dis., 91, 1(1952).

11. Salle, A. J., Fundamental Principles of Bacteriology, McGraw-Hill Book Company, Inc., New York, 1961.

12. Quist, K. D., "*Salmonella* in Poultry as Related to Human Health", U.S. Dept. of Agric., Report of National Plans Conference, 24-30, November, 1962.

13. Lafton, C. B., S. M. Morrison, and P. D. Leiby, "The *Enterobacteriaceae* of Some Colorado Small Mammals and Birds, and Their Possible Role in Gastroenteritis in Man and Domestic Animals", Zoonoses Res., 1, 277 (1962).

14. Summers, J. L., "The Sanitary Significance of Pollution of Waters by Domestic and Wild Animals : A Literature Review", U. S. Dept. of Health, Education and Welfare, P. H. S., Shellfish Sanitation Technical Report, 1967.

15. Janssen, W. A., and C. D. Meyers, "Fish : Serological Evidence of Infection with Human Pathogens", Science, 159, 547 (1968).

16. Andre, D. A., H. H. Weiser, and G. W. Maloney, J. Amer. Water Works Assoc., 59, 503 (1967).

17. Wang, W. L. L., S. G. Dunlop, and P. S. Munson, "Factors Influencing the Survival of *Shigella* in Wastewater and Irrigation Water", JWPCF, 38, 1775 (1966).

18. Babbitt, H. E., J. J. Doland, and J. L. Cleasby, Water Supply Engineering, McGraw-Hill Book Company, Inc., 1962.

19. Hentges, D. J., "Inhibition of *Shigella flexneri* by the Normal Intestinal Flora", J. Bacteriology, 97, 513 (1969).

20. Geldreich, E. E., and N. A. Clarke, "Bacterial Pollution Indicators in the Intestinal Tract of Freshwater Fish", Applied Microbiology, 14, 429 (1966).

21. Howell, D., "Leptospirosis in Dairy Cows", Vet. Rec., 84, 122 (1969).

22. Schuffner, W., "Recent Work on Leptospirosis", Trans. Royal Soc. Trop. Mec. Hyg., 28, 7 (1939).

23. Clark, L., J. I. Kresse, R. R. Marshak, and C. J. Hallister, "*Leptospira grippotyphosa* Infections in Cattle and Wildlife in Pennsylvania", J. Amer. Vet. Med. Assoc., 141, 710 (1962).

24. Chang, S. L., M. B. Buckingham, and M. P. Taylor, "Studies on *Leptospira icterohaemorrhagiae*", J. Infect. Diseases, 82, 256 (1948).

25. Kittrell, F. W., and S. A. Furfari, "Observations of Coliform Bacteria in Streams", JWPCF, 35, [36] (1963).

26. Hanes, N. B., and R. Fragala, "Effect of Seawater Concentration on Survival of Indicator Bacteria", JWPCF, 39, 97 (1967).

27. Mitchell, R., "Factors Affecting the Decline of Non-Marine Micro-Organisms in Seawater", *Water Research*, 2, 535 (1968).

28. Gareeb, A. H. A., "The Detection of Cholera vibrios in Calcutta Waters : The River Hoogly and Canals", *J. Hygiene*, 58, 2, (1960).

29. Sen., R., and B. Jacobs, "Pathogenic Intestinal Organisms in the Unfiltered Water Supply and the Effect of Chlorination", *Indian J. Med. Res.*, 57, 1220 (1969).

30. Fair, Gordon M., John C. Geyer, Daniel A. Okun, "Water and Wastewater Engineering", Volume 2, *Water Purification and Wastewater Treatment and Disposal*, *John Wiley & Sons, Inc.*, New York, 1968.

31. Eliassen, Rolf, "Coliform Aftergrowths in Chlorinated Storm Overflows", *J. of the Sanitary Engineering Division*, Proc. ASCE, 94: SA2, 371 (1968).

32. New Orleans Board of Health, Personal Communication.

33. Chlorine Bleach Solutions, Bulletin No. 14, Solvay Technical and Engineering Service, Allied Chemical Corporation, 1965.

SECTION XIV

PROJECT PATENTS AND PUBLICATIONS

1. Patent 3,702,234 - A method for forming sodium hypochlorite at atmospheric conditions from sodium hydroxide and chlorine in proper proportions and under controlled conditions to prevent the escape of unreacted chlorine to the atmosphere; and to avoid the formation of sodium chlorate.

2. Pavia, E. H., "Chlorination and Hypochlorination of Polluted Storm Water at New Orleans", presented at the 31st Annual Short Course for Water, Sewerage and Industrial Waste Disposal, Louisiana State University, March 14, 1968.

3. Pavia, E. H. and C. J. Powell, "Stormwater Disinfection at New Orleans", presented at 41st Annual Conference of Water Pollution Control Federation, Chicago, Ill., Sept. 22-27, 1968, also, JWPCF, 41:4, 591 (1969) 41:4.

4. Pavia, E. H. and C. J. Powell, "Hypochlorination of Storm Water Run Off at New Orleans", presented at Annual Meeting of American Shore & Beach Preservation Association, New Orleans, La., Nov. 14-16, 1968, Shore and Beach, 37:1, (1969).

5. Brown, L. R.,E. H. Pavia, "Lake Pontchartrain Storm Water Pollution Control Project", presented at American Society of Civil Engineers Meeting on Water Resources Engineering, New Orleans, La., Feb. 3-7, 1969.

SECTION XV

GLOSSARY & ABBREVIATIONS

DEFINITIONS

Analysis of Variance - A statistical technique which analyzes the variance which can be attributed to each of several factors which were varied singly or combination.

Benthic Deposits - Deposits of living, bottom dwelling organisms in a stream.

Cells - In Analysis of Variance a cell contains all the replicate values for one position in a factorial arrangement.

Chlorine Demand - The demand for chlorine in a volume of water caused by organic and inorganic reductants. This quantity is defined as the difference between an initial chlorine concentration in a specific volume of water and the total available chlorine remaining at the end of a contact period.

Coliform, Coliform Bacteria - All the aerobic and facultative anaerobic, Gram - negative, nonspore - forming rod shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C. Used as an indicator of bacterial pollution.

Crazing - Fine or small cracks in a surface.

Diffussion - The transport in a given direction at a point in a flow due to the difference between the true convection in that direction and the time average of the convection in that direction.

Dispersion - The transport in a given direction at a point in a flow due to the difference between the true convection in that direction and the spatial average of the convection in that direction.

Enterococci - A group of bacteria consisting of anaerobic spore-forming rods which indicate recent fecal pollution, sometimes referred to as fecal streprococci.

Factorial Arrangement - A method for apportioning the number of tests required for an Analysis of Variance. Given the formula $N=X^k$ where X is the number of independent variables and k is the number of levels (factors).

Fecal Coliform - Coliforms derived from the gut of warm blooded animals, test results expressed in terms of density in a given volume of water.

Fibrous Glass Plastic - A laminar material having glass fibers embedded in a plastic region to provide structural strength.

Membrane Filter Technique - A direct plating technique to determine the density of coliform bacteria in a given volume of water.

Multiple Tube Technique - A technique to determine the density of coliform bacteria in a given volume of water carried out by dividing the sample into multiple portions and testing each portion individually.

Nitrogen (Ammonia) - A product of microbiologic activity sometimes accepted as evidence of sanitary pollution in surface waters.

ORP - Oxidation Reduction Potential - Oxidation Reduction Potential (a precise measurement for the determination and control of minute concentration of oxidant and reductants in solution).

Pathogen - A microorganism capable of causing disease.

Sodium Hypochlorite - A salt of hypochlorous acid formed by reacting chlorine with sodium hydroxide, which exhibits greater stability than the acid. It is used for disinfection and bleach in place of the acid.

Solids Series - A series of tests to determine the solids content of wastewater. They consists of the residue on evaporation, total volatile and fixed residue, total volatile and fixed suspended matter, dissolved matter, and settleable matter.

Spectral Analysis - Statistical techniques which utilize the Fourier or Laplace transforms of functions rather than the functions themselves.

Stochastic - The property of being random with respect to time.

Suspended Solids - The filterable residue in water.

Thermal Coefficient of Expansion - A number of expressing unit change in volume of a material due to a unit change in temperature.

Ton Of Refrigeration - A unit of refrigeration equivalent to 288,000 BTU per day.

cfd - Cubic Feet per day

cfs - Cubic Feet per second

Cl_2 - Chlorine

COD - Chemical Oxygen Demand - A measure of the oxygen equivalent of that portion of the organic matter in a sample that is subject to oxidation by a strong chemical oxidant.

DO - Dissolved Oxygen - The density of oxygen in solution in a given sample of water.

DPS - Drainage Pumping Station

°F - Degrees Fahrenheit

gals. - Gallons

gpd - Gallons per day

gpl - Grams per liter

mg/l - Milligrams per liter

ml - Milliliter

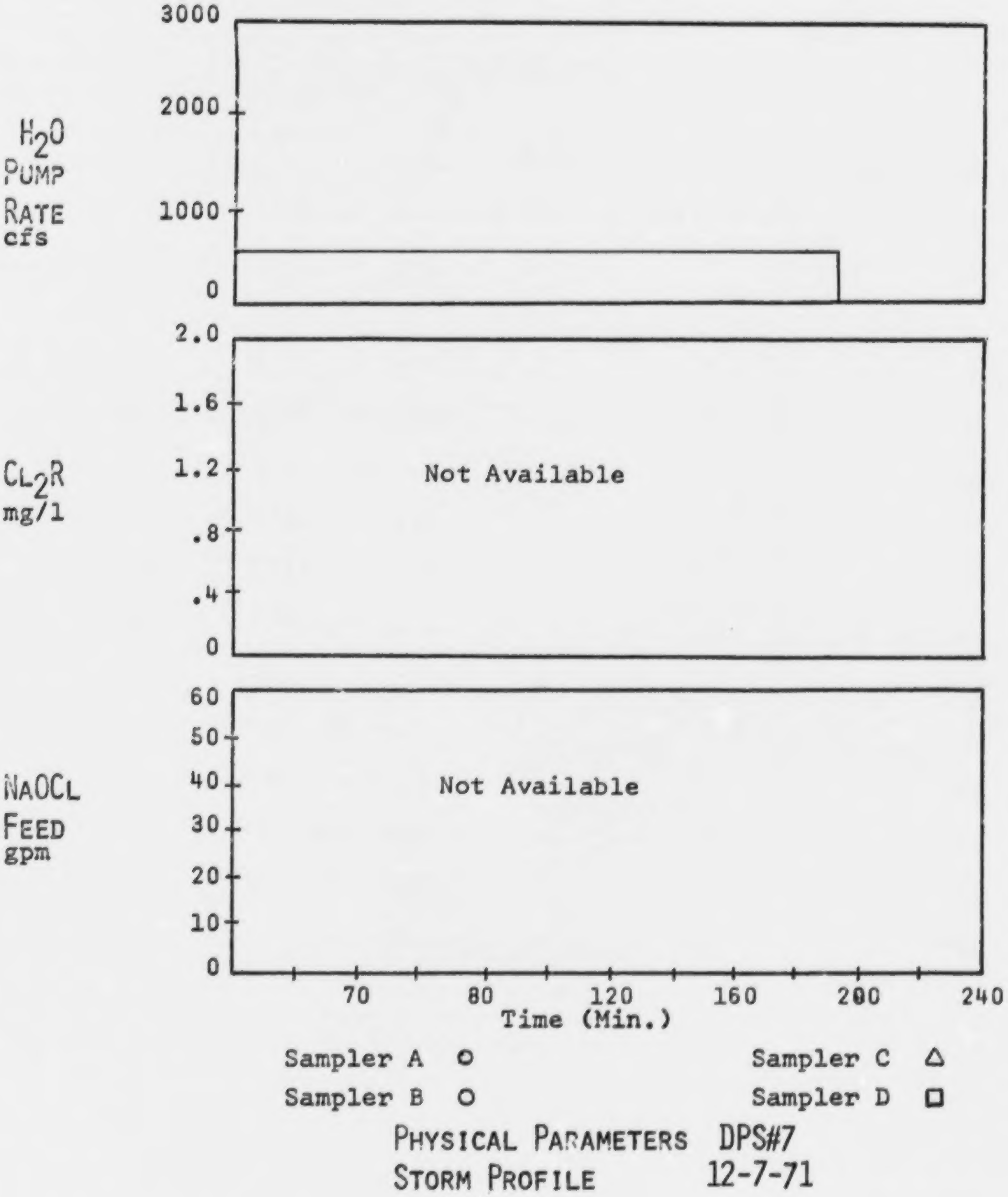
NaOCl - Sodium Hypochlorite

NaOH - Sodium Hydroxide

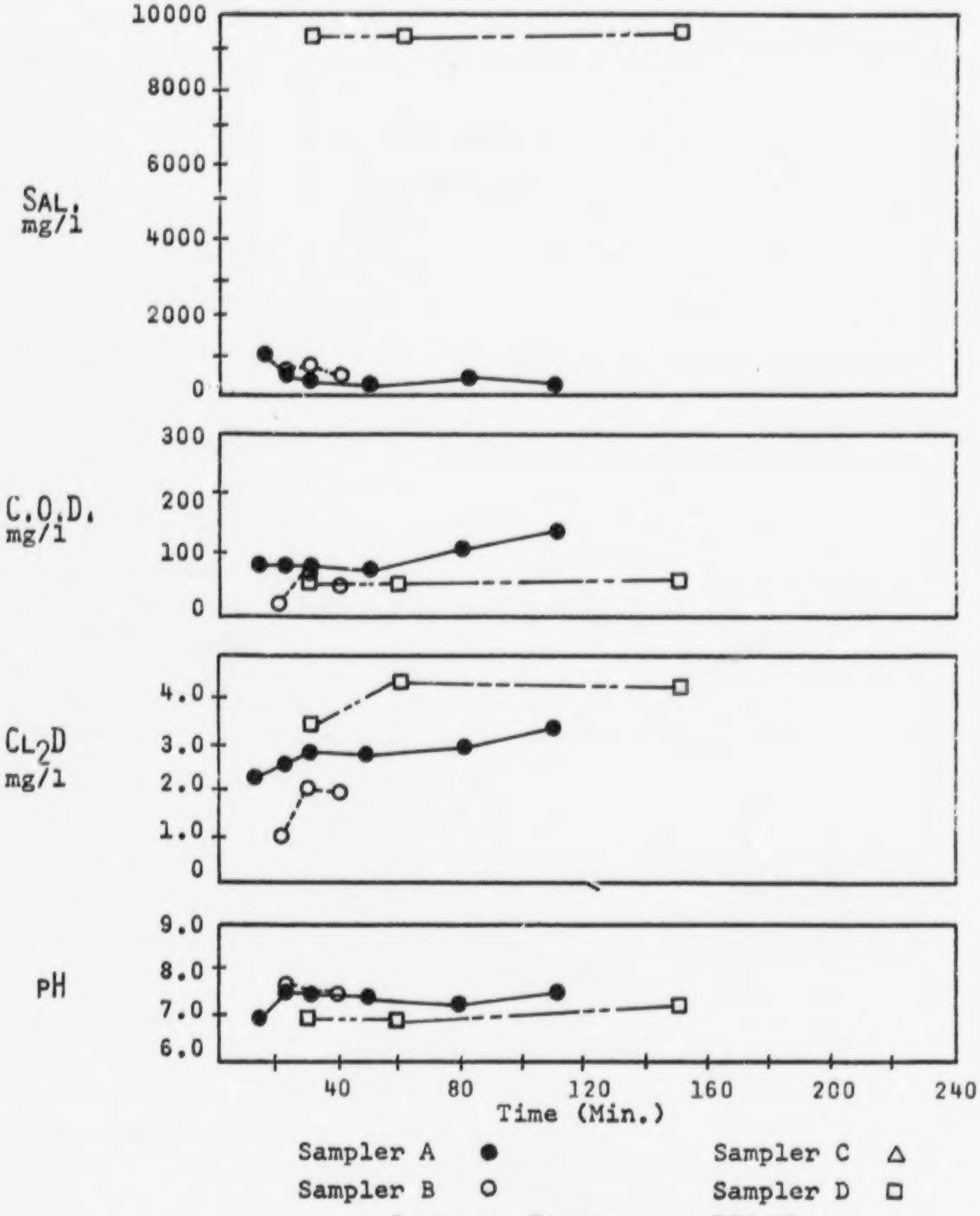
SECTION XVI

APPENDICES

No.	Title		Page No.
1	Storm Profile, DPS #7,	Dec. 7, 1971	144-146
2	" "	Feb. 7, 1972	147-149
3	" "	Mar. 2, 1972	150-152
4	" "	Mar. 9, 1972	153-155
5	" "	Mar. 19, 1972	156-158
6	" "	May 11, 1972	159-161
7	" "	May 12, 1972	162-164
8	" "	June 9, 1972	165-167
9	" "	July 5, 1972	168-170
10	" "	July 12, 1972	171-173
11	" "	July 13, 1972	174-176
12	" "	July 20, 1972	177-179
13	" "	Sep. 30, 1972	180-182
14	" "	Oct. 22, 1972	183-185
15	" "	Nov. 4, 1972	186-188

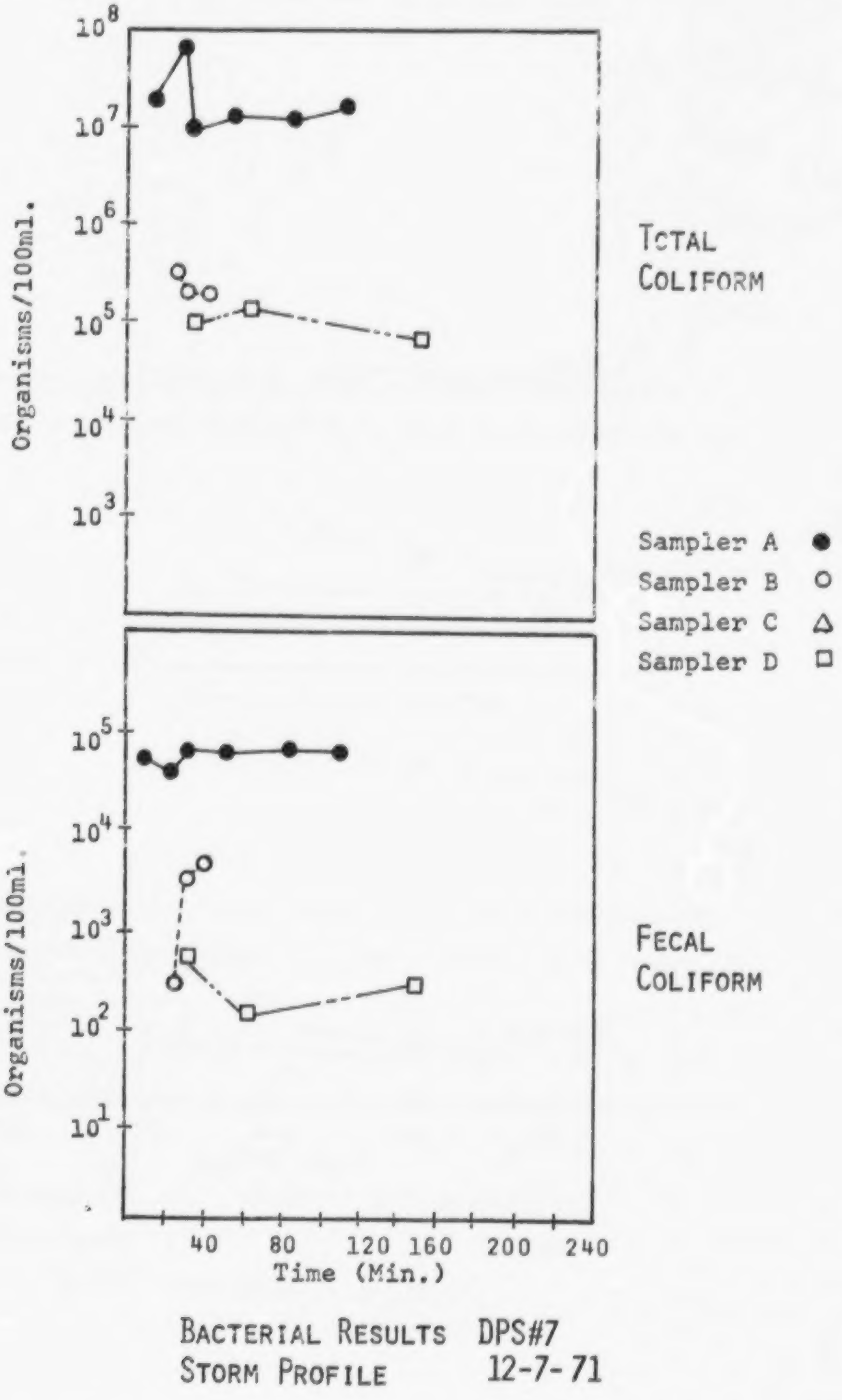


Appendix 1-1 Storm Profile, DPS #7, Dec. 7, 1971

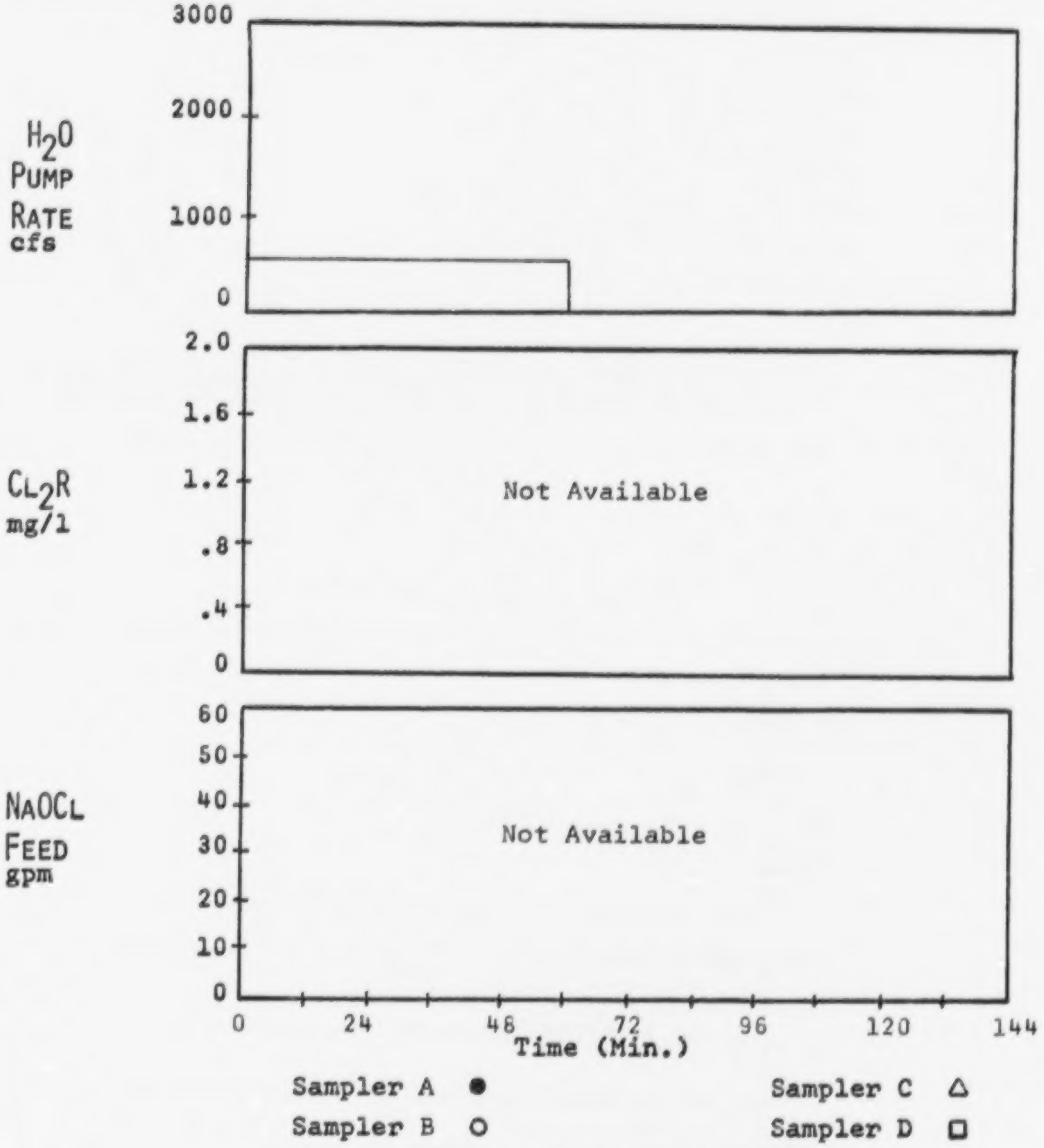


CHEMICAL PARAMETERS DPS #7
STORM PROFILE 12-7-71

Appendix 1-2 Storm Profile, DPS #7, Dec. 7, 1971

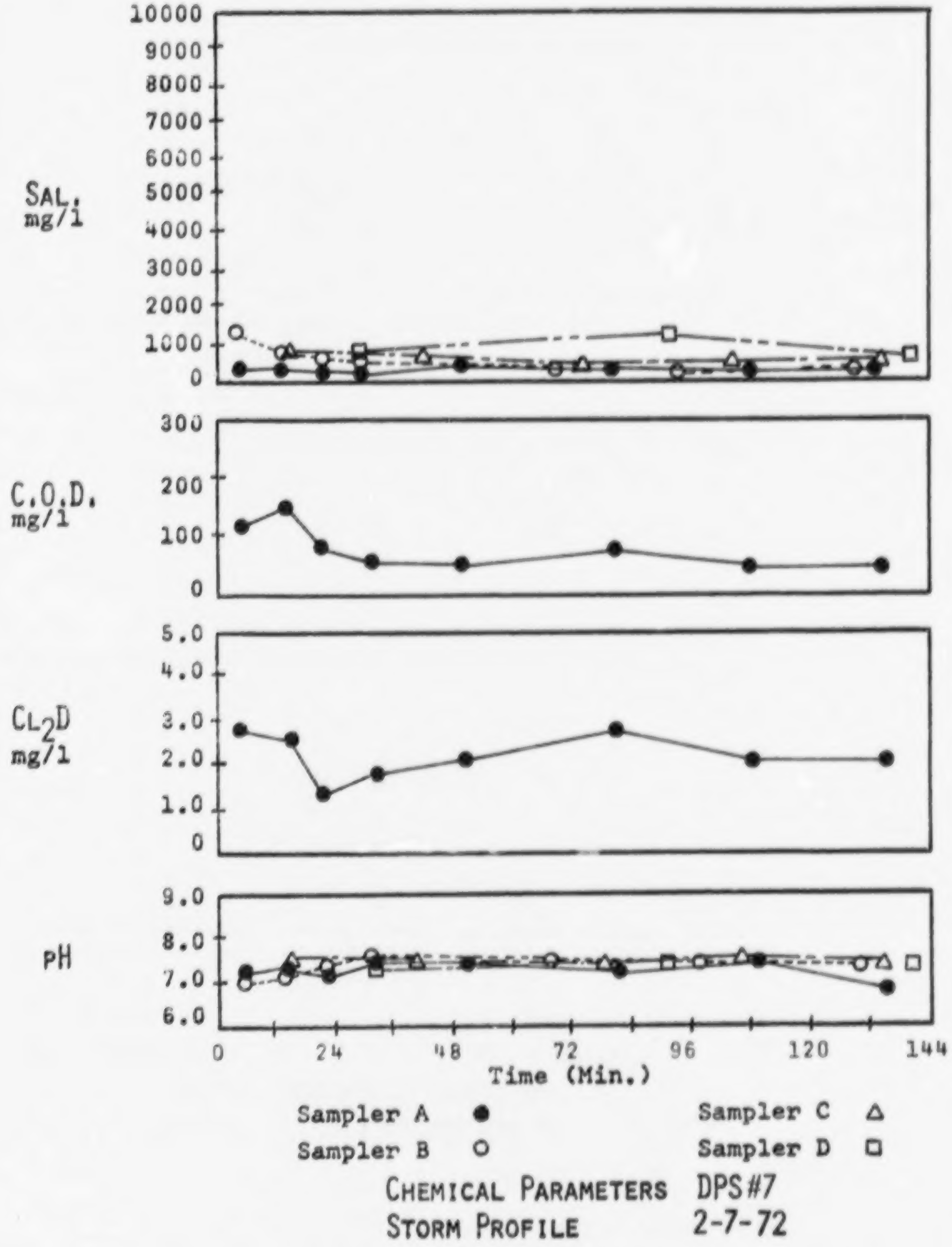


Appendix 1-3 Storm Profile Results, DPS #7,
Dec. 7, 1971

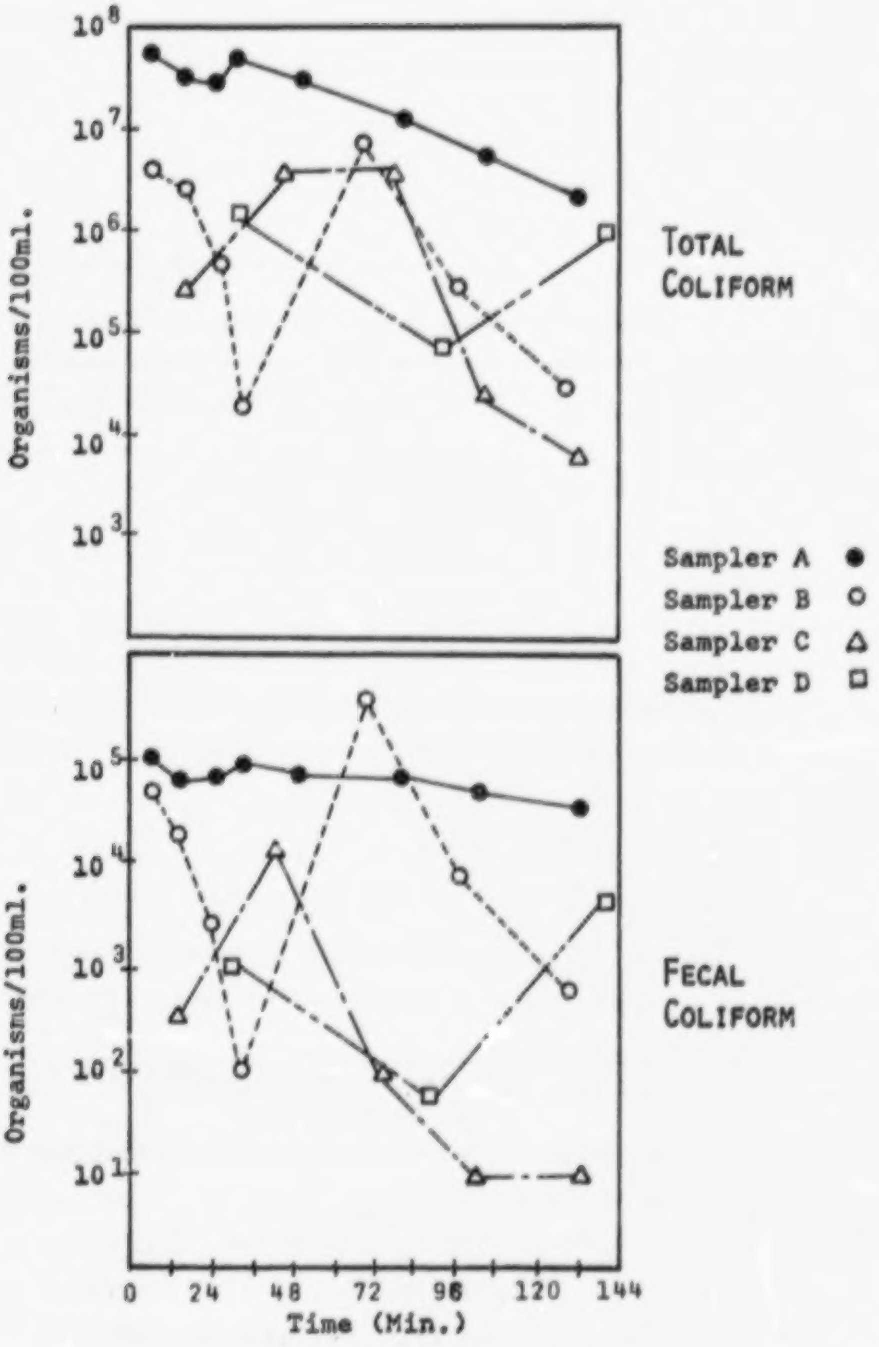


PHYSICAL PARAMETERS DPS#7
STORM PROFILE 2-7-72

Appendix 2-1 Storm Profile, DPS #7, Feb 7,1972

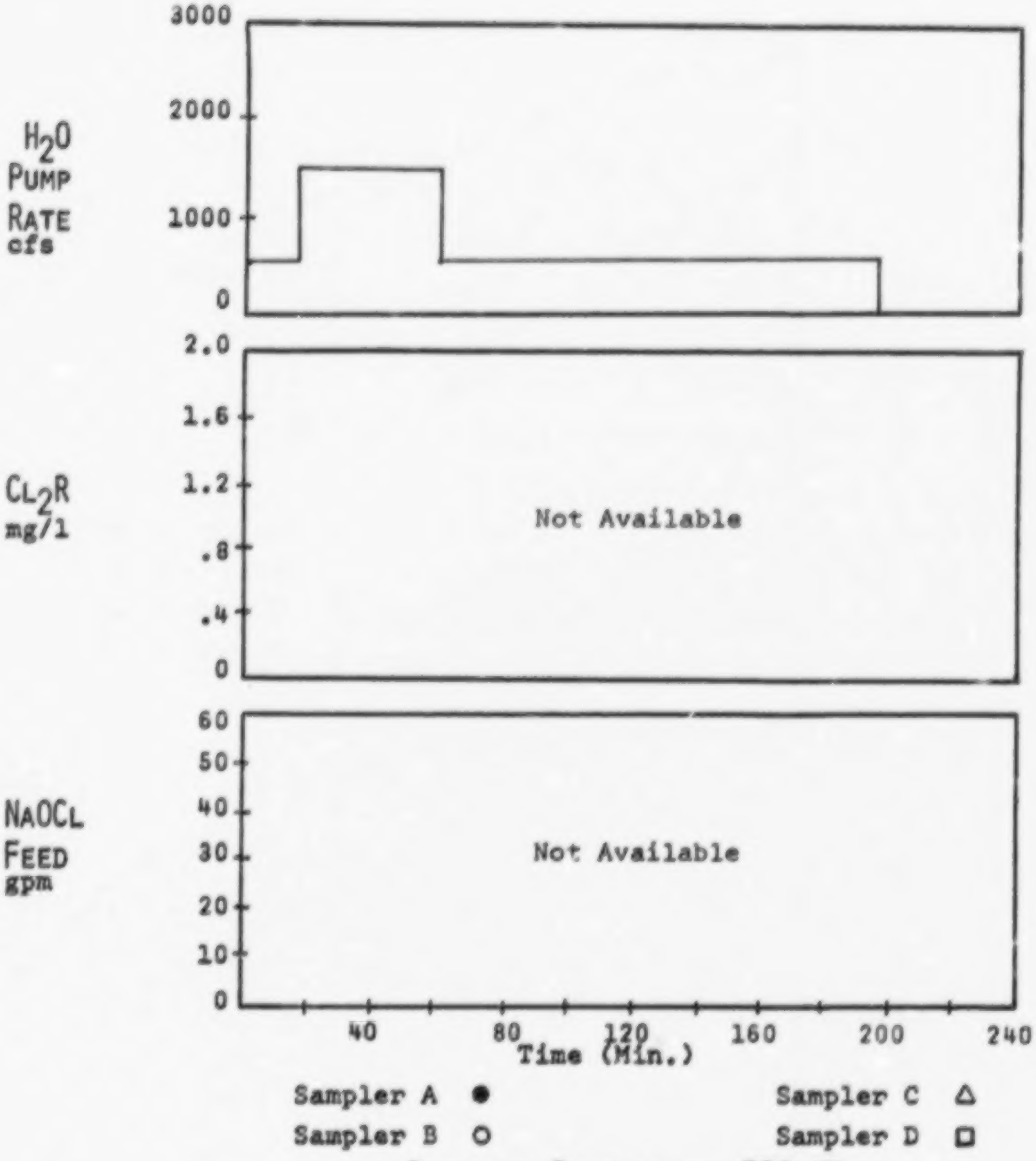


Appendix 2-2 Storm Profile, DPS #7, Feb. 7, 1972



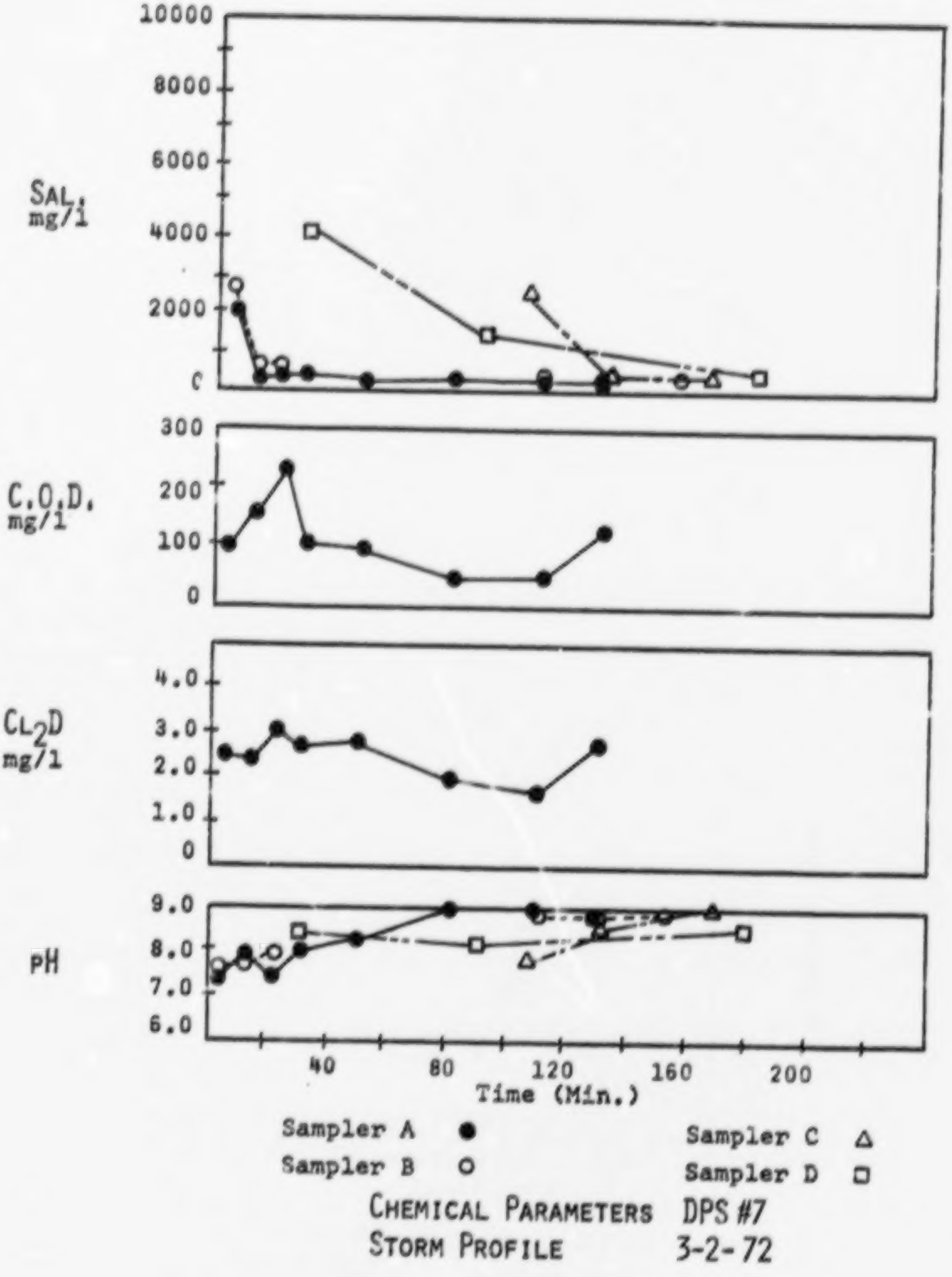
BACTERIAL RESULTS DPS#7
STORM PROFILE 2-7-72

Appendix 2-3 Storm Profile, DPS #7, Feb. 7, 1972

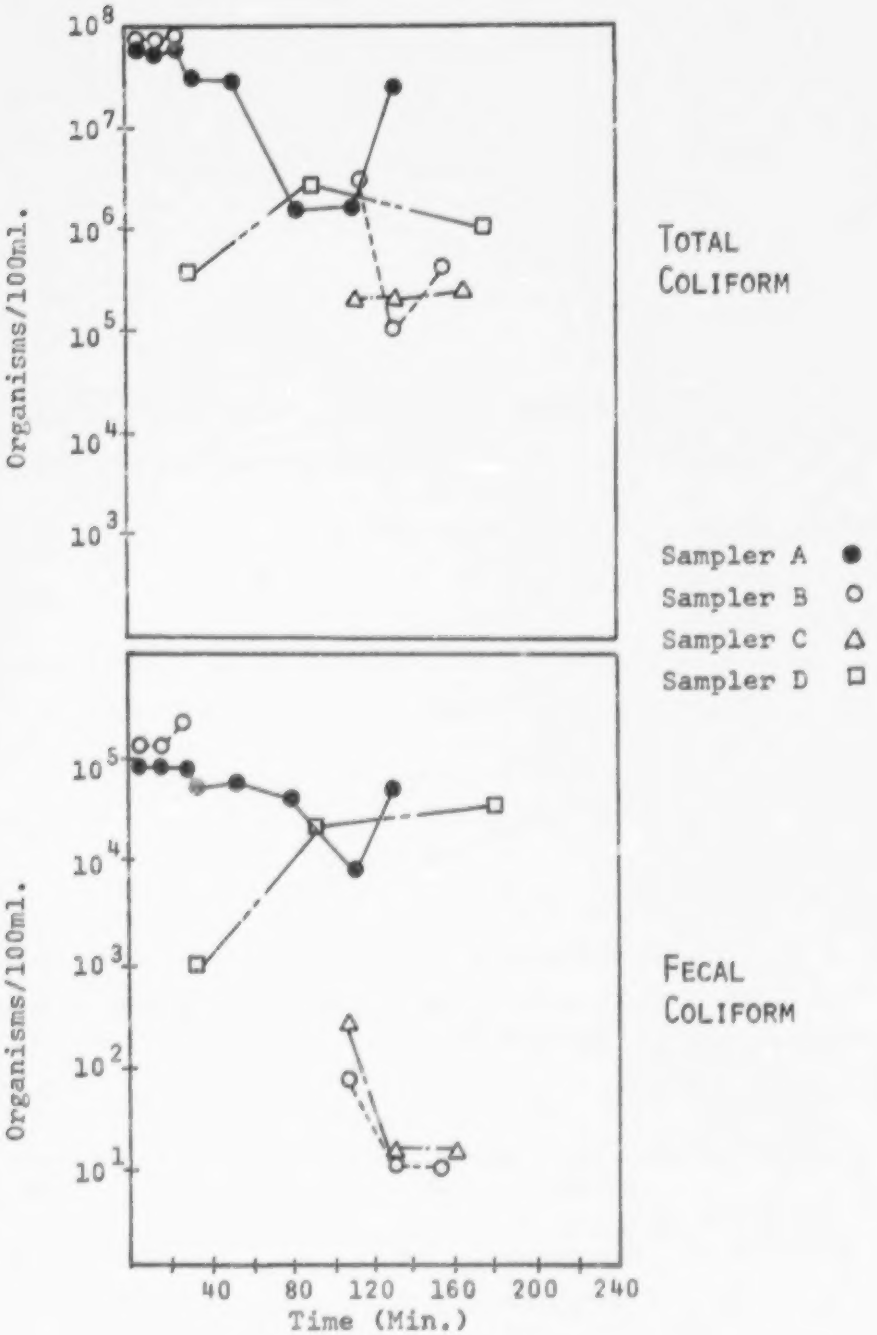


PHYSICAL PARAMETERS DPS #7
STORM PROFILE 3-2-72

Appendix 3-1 Storm Profile, DPS #7, Mar. 2, 1972

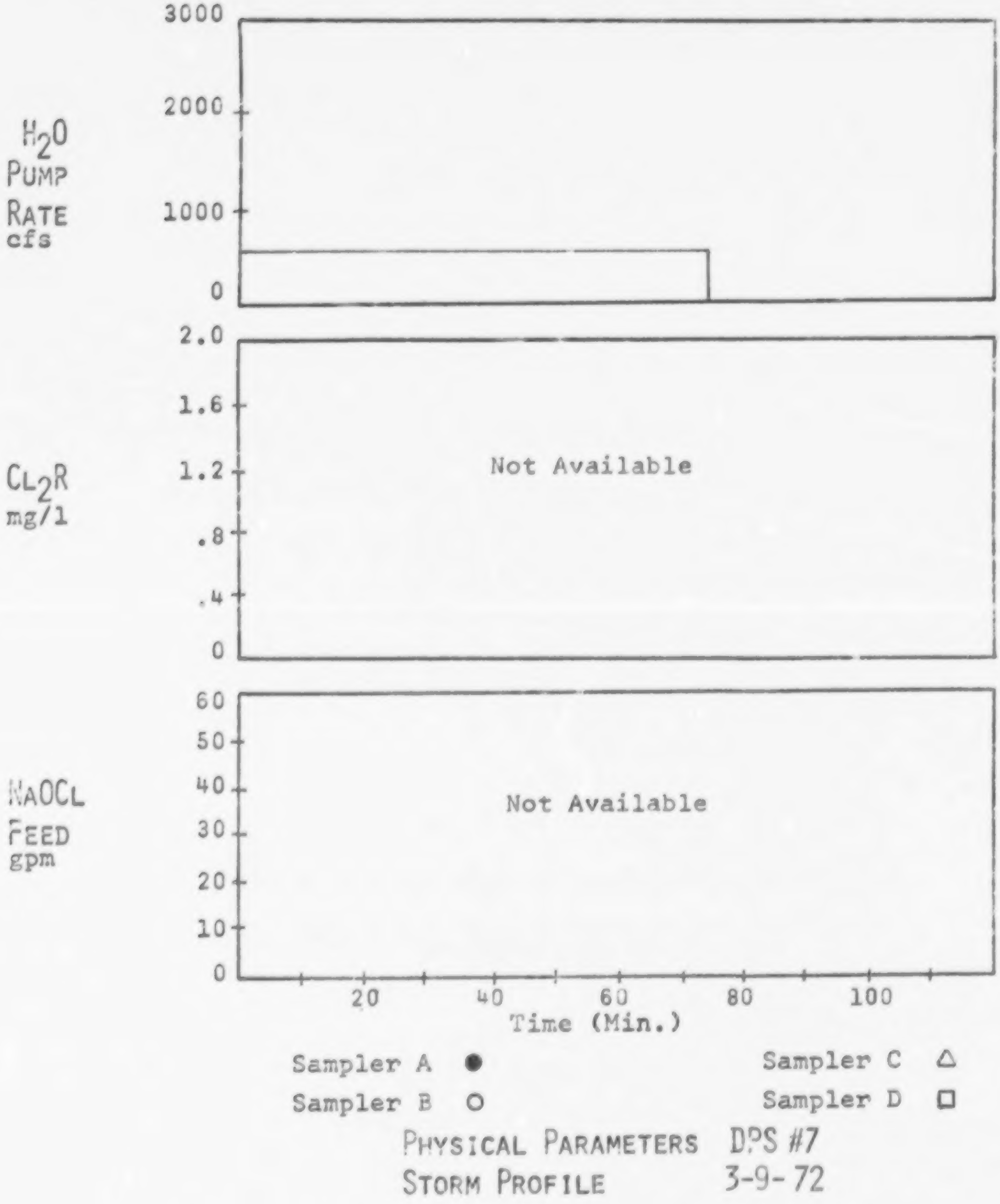


Appendix 3-2 Storm Profile, DPS #7, Mar. 2, 1972

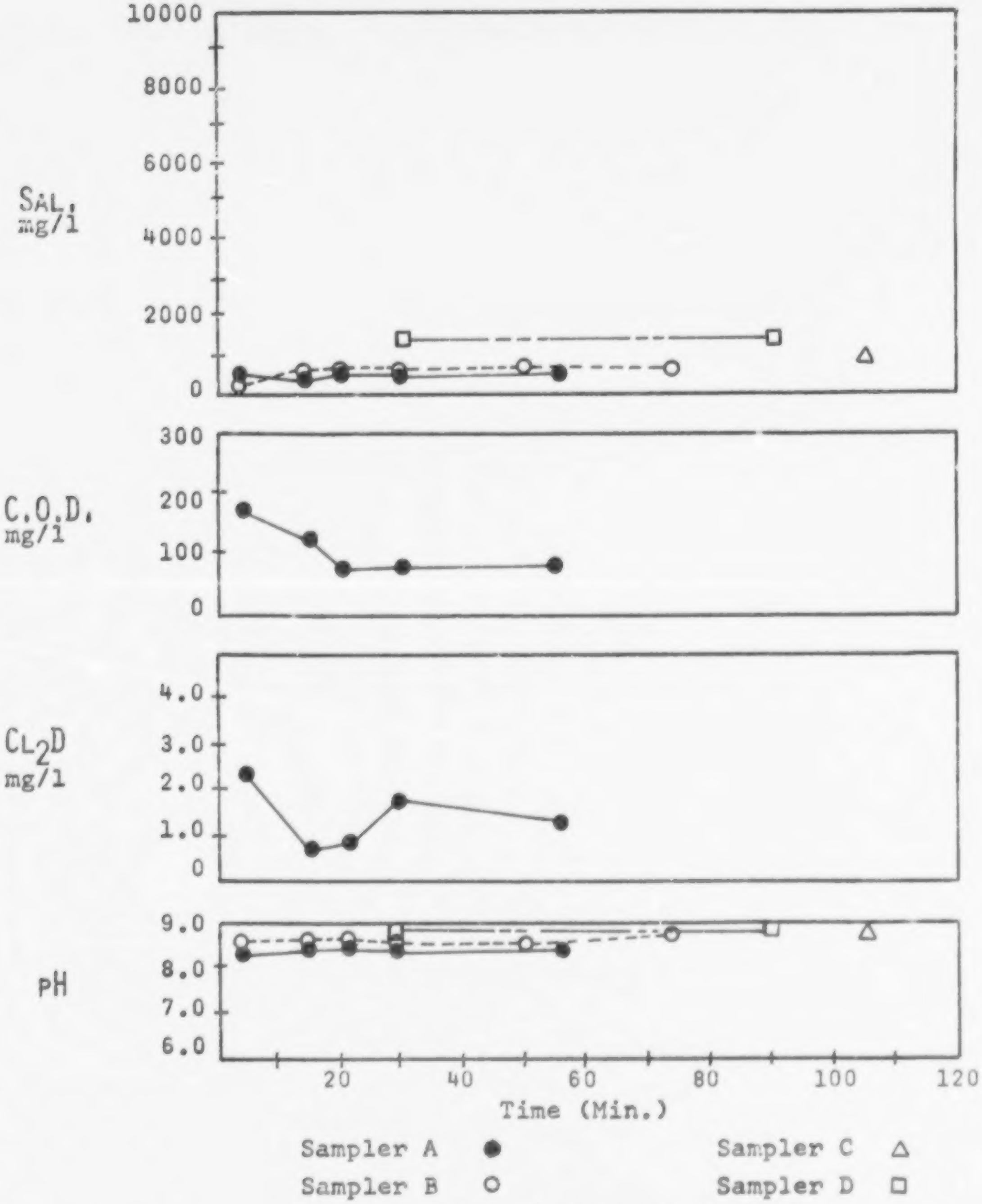


BACTERIAL RESULTS DPS #7
STORM PROFILE 3-2-72

Appendix 3-3 Storm Profile Results, DPS #7, Mar.2, 1972

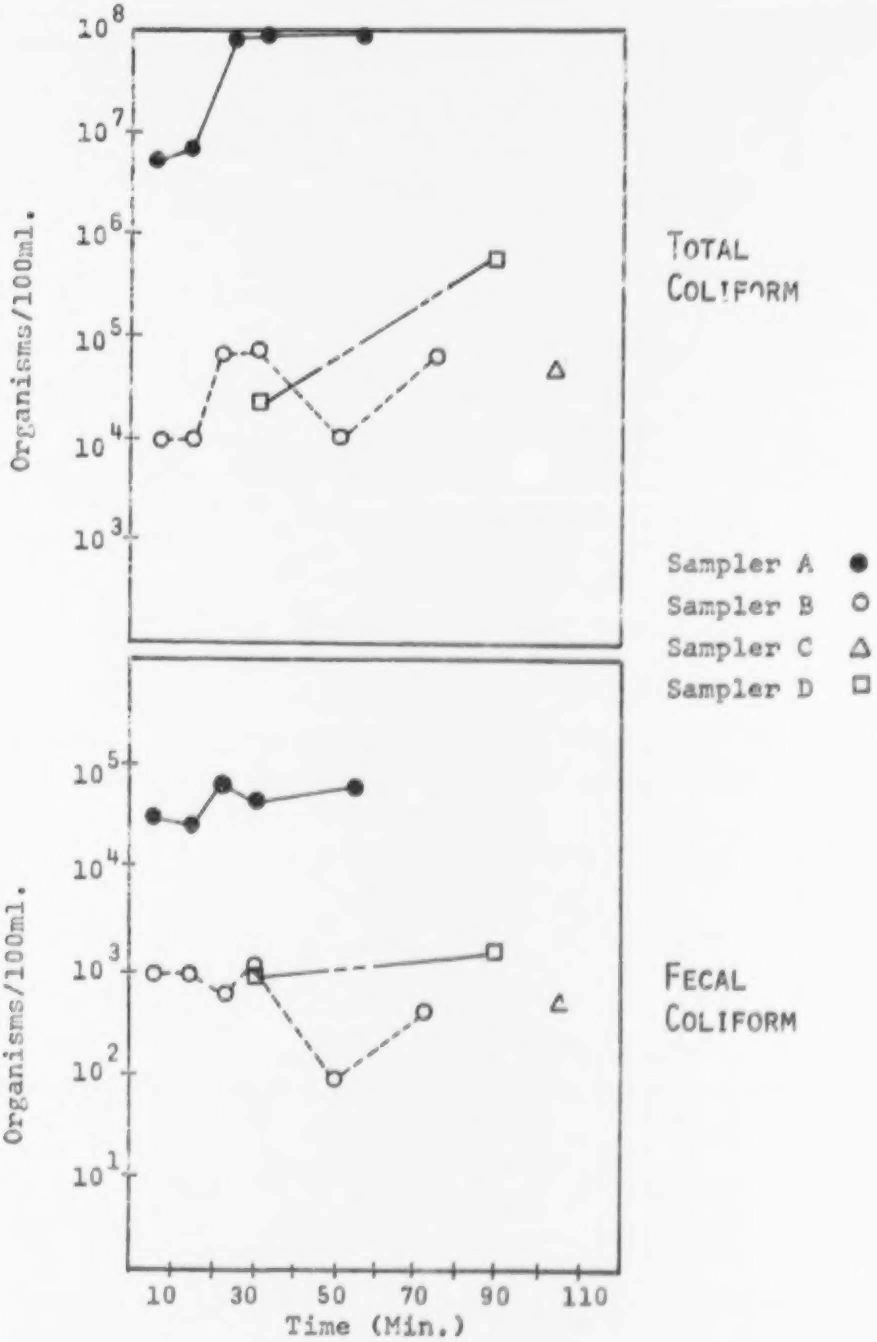


Appendix 4-1 Storm Profile, DPS #7, Mar. 9, 1972



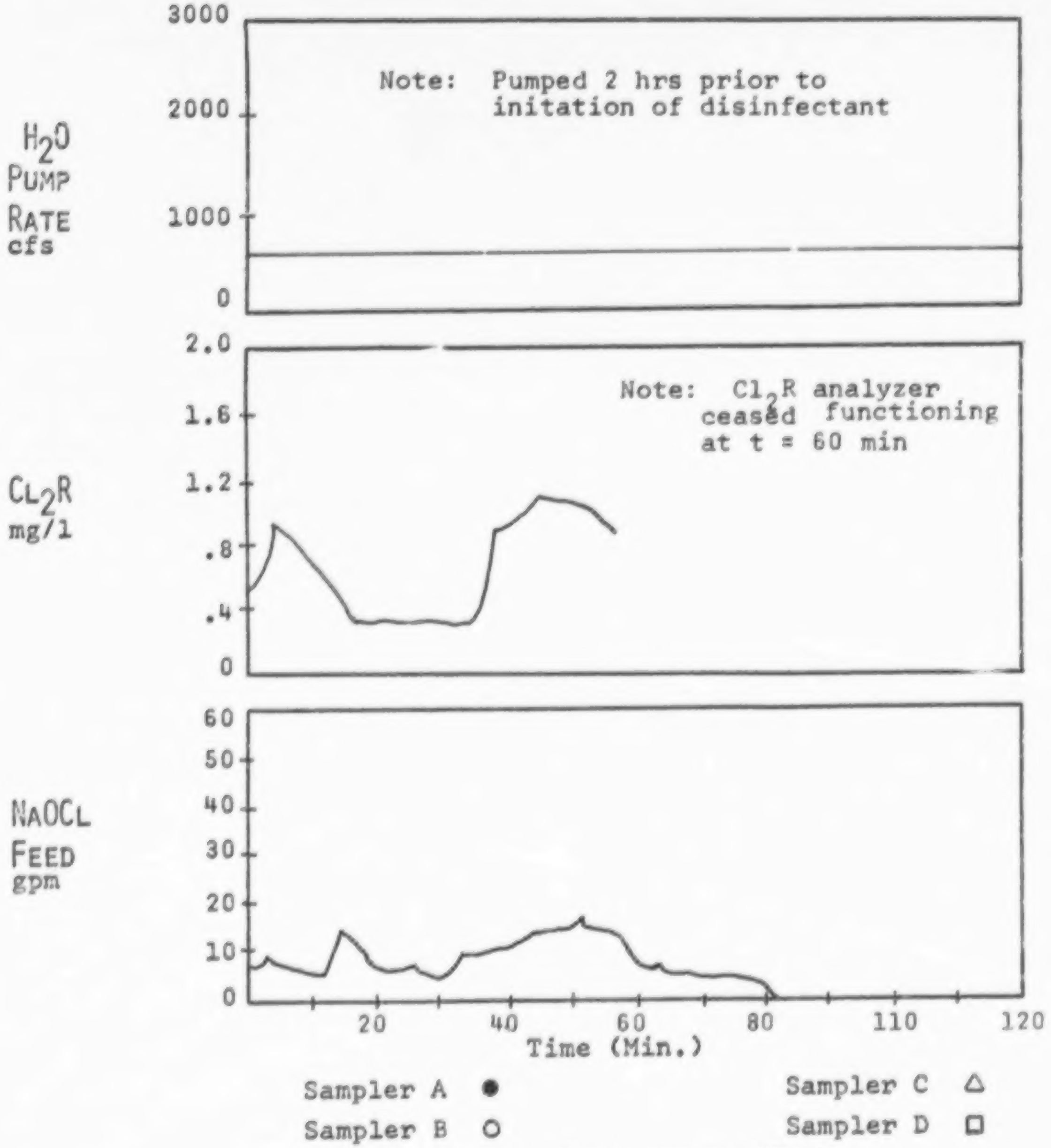
CHEMICAL PARAMETERS DPS #7
STORM PROFILE 3-9-72

Appendix 4-2 Storm Profile, DPS #7, Mar. 9, 1972



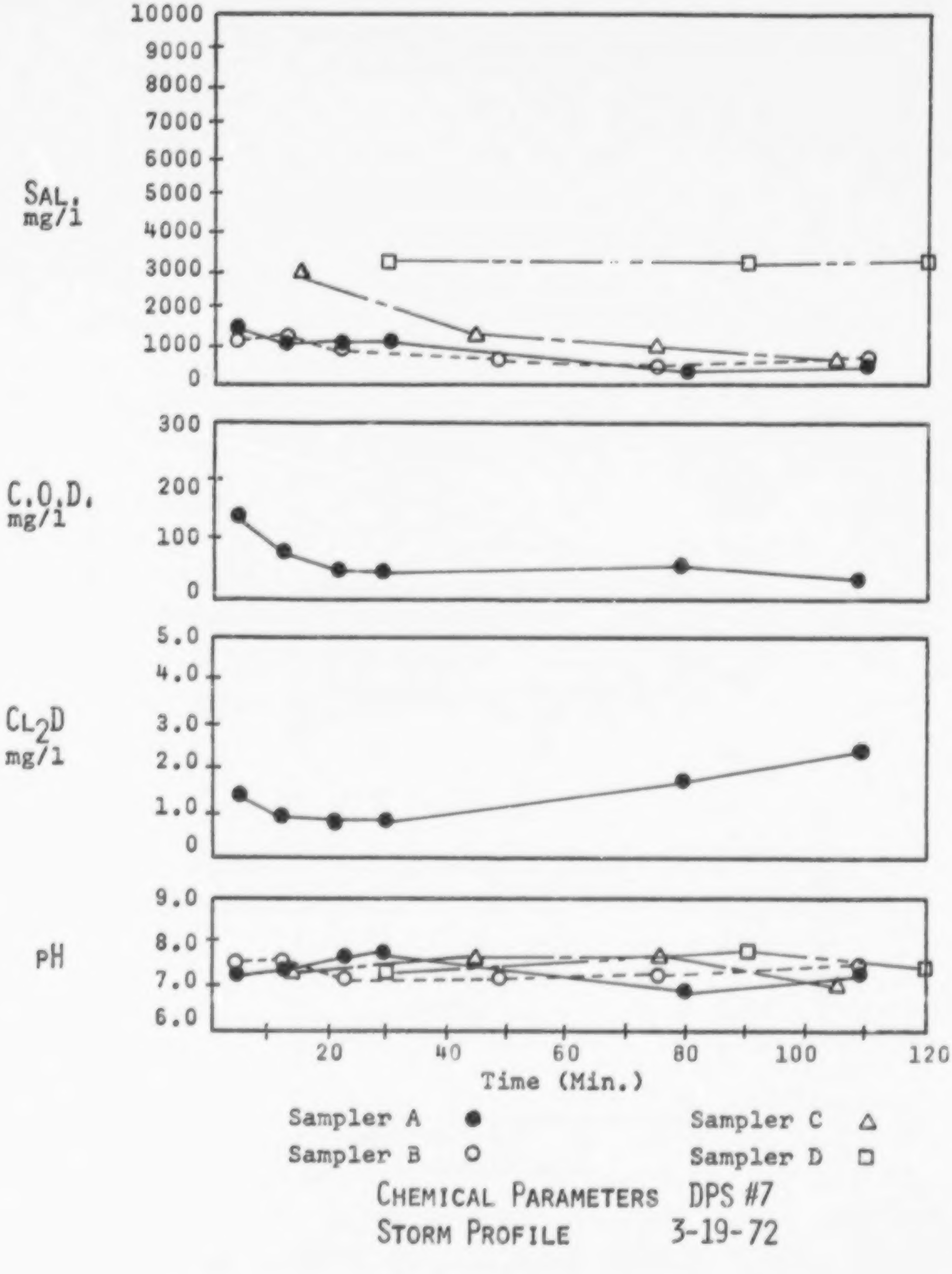
BACTERIAL RESULTS DPS #7
STORM PROFILE 3-9-72

Appendix 4-3 Storm Profile Results, DPS #7, Mar. 9, 1972

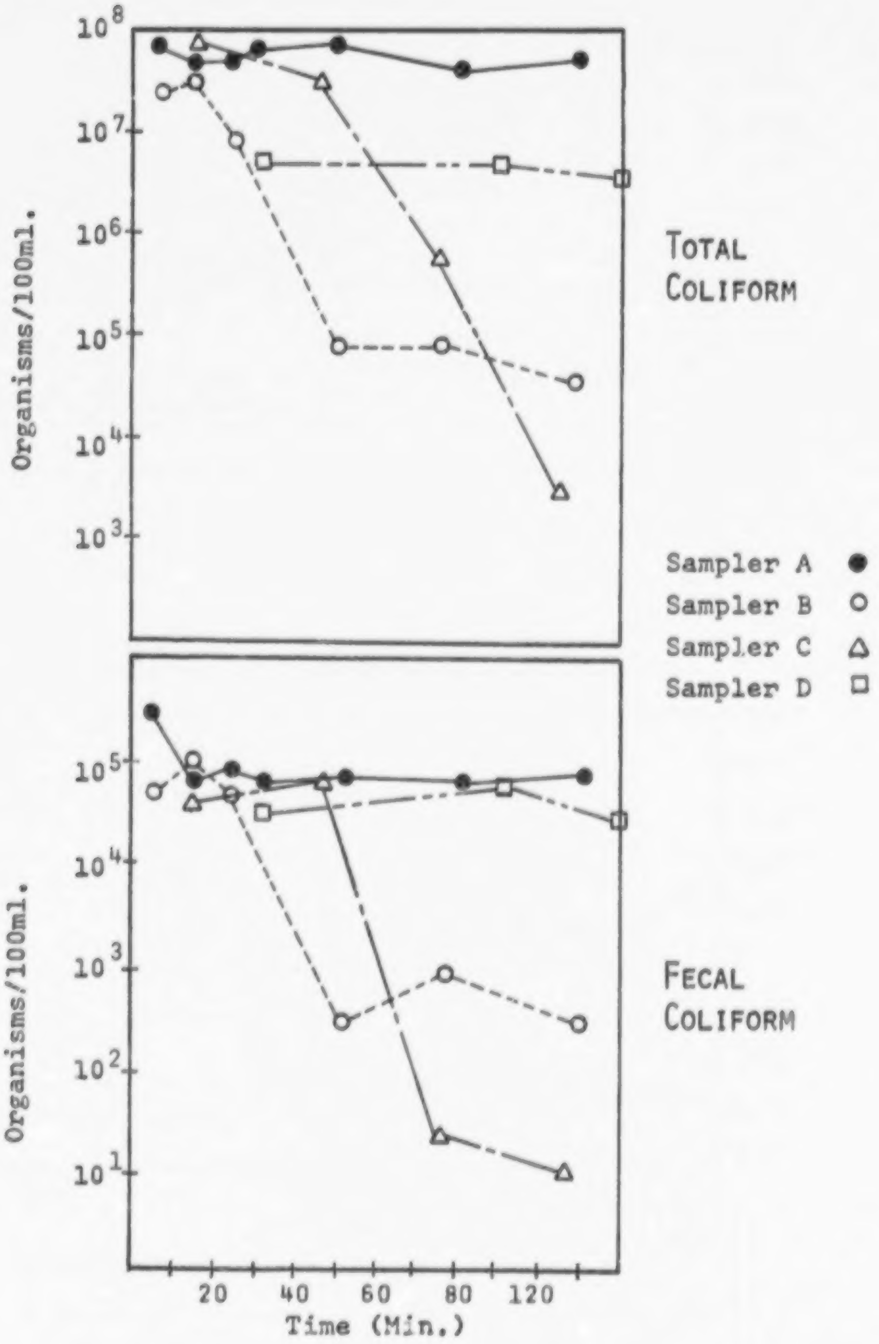


PHYSICAL PARAMETERS DPS #7
STORM PROFILE 3-19-72

Appendix 5-1 Storm Profile, DPS #7, Mar. 19, 1972

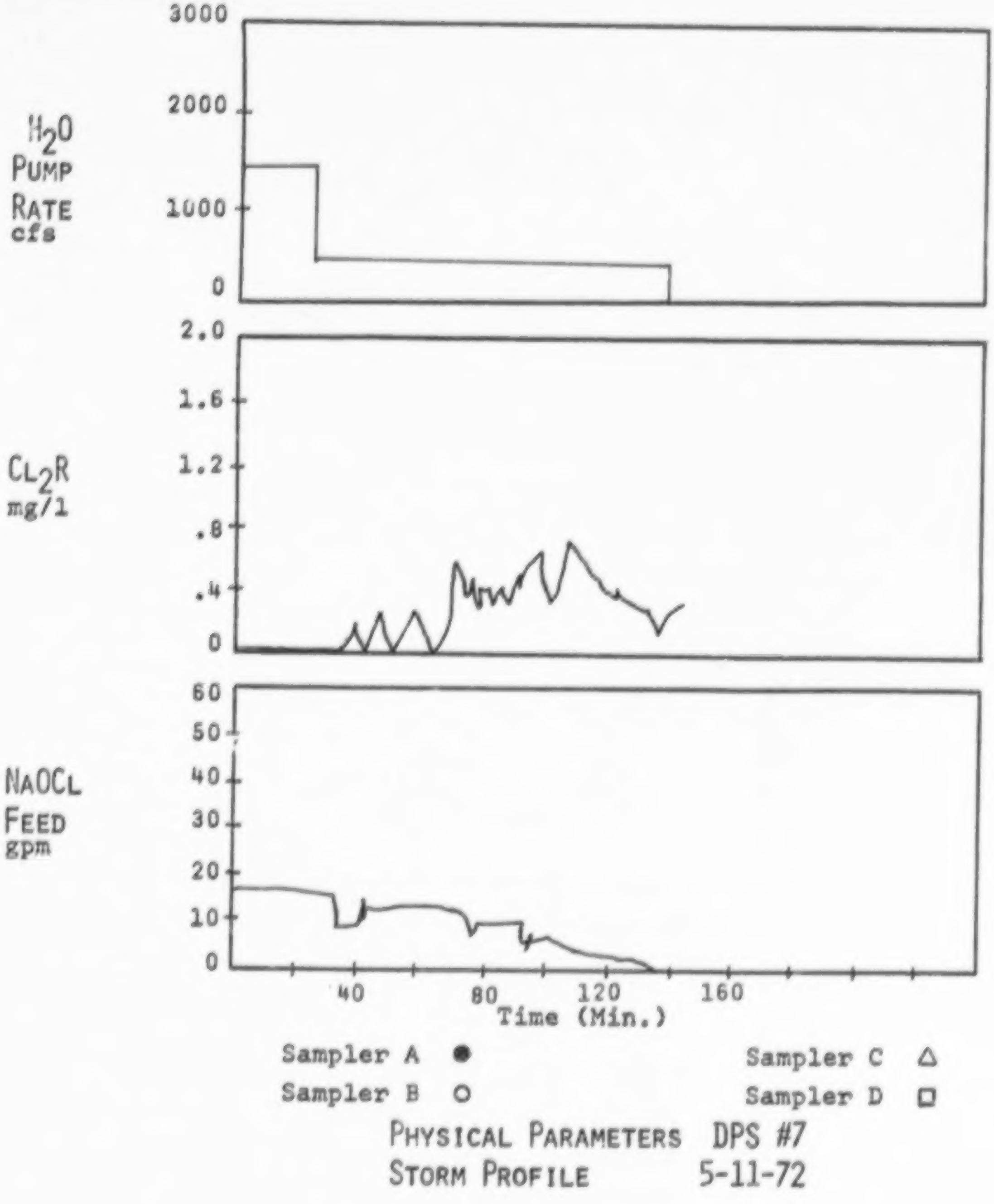


Appendix 5-2 Storm Profile, DPS #7, Mar. 19, 1972

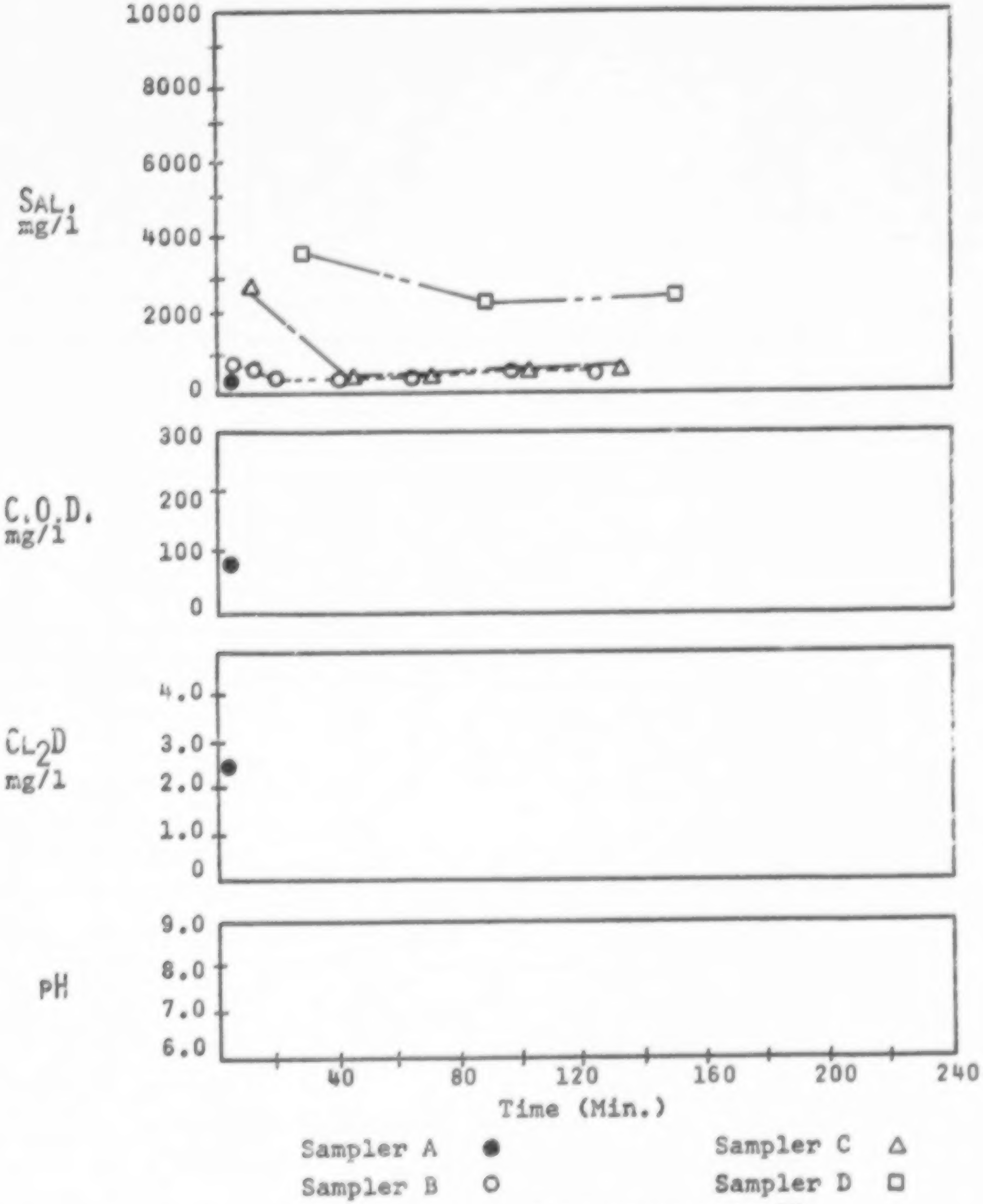


BACTERIAL RESULTS DPS #7
STORM PROFILE 3-19-72

Appendix 5-3 Storm Profile Results, DPS #7, Mar. 19, 1972

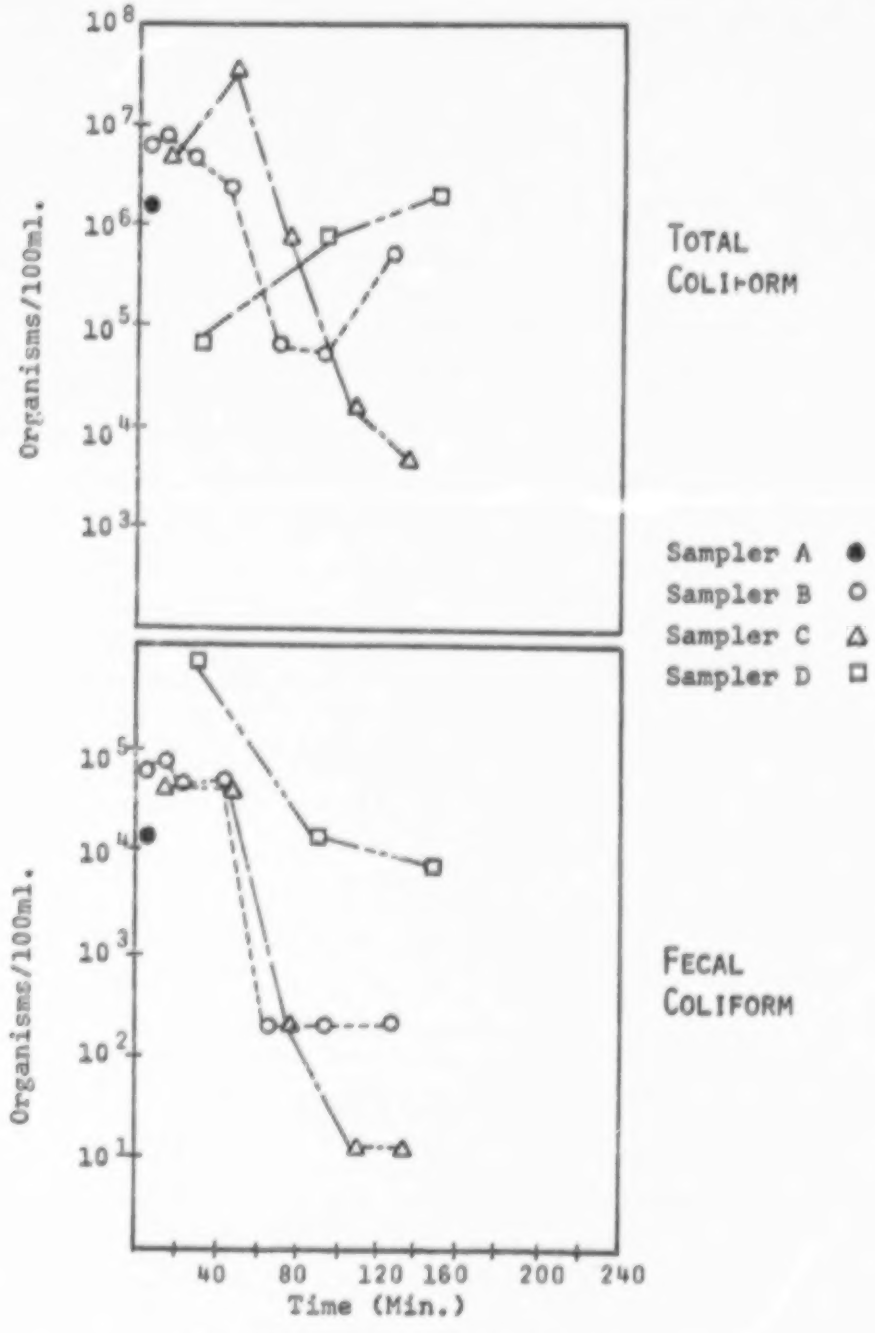


Appendix 6-1 Storm Profile, DPS #7, May 11, 1972



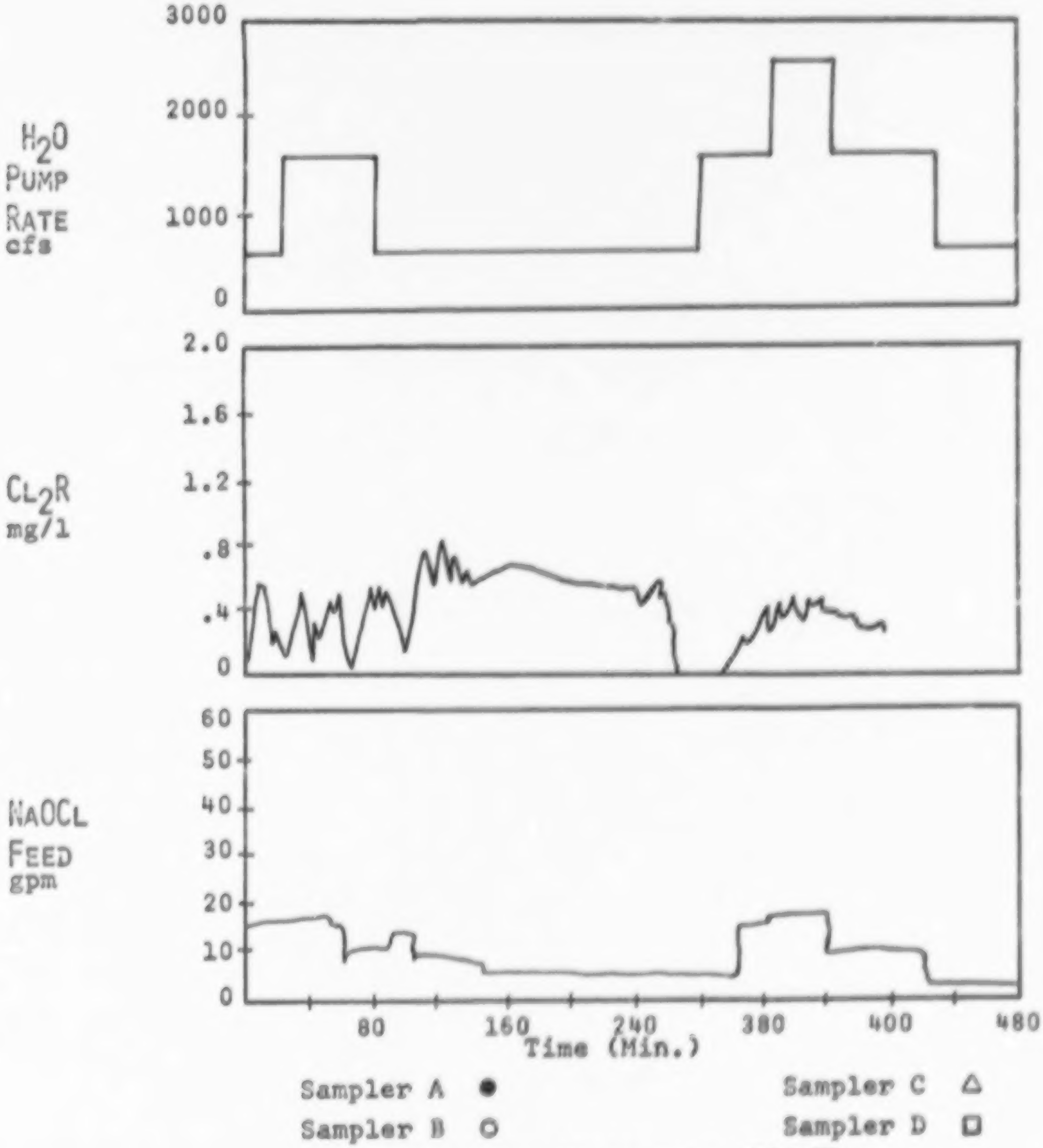
CHEMICAL PARAMETERS DPS #7
STORM PROFILE 5-11-72

Appendix 6-2 Storm Profile, DPS #7, May 11, 1972



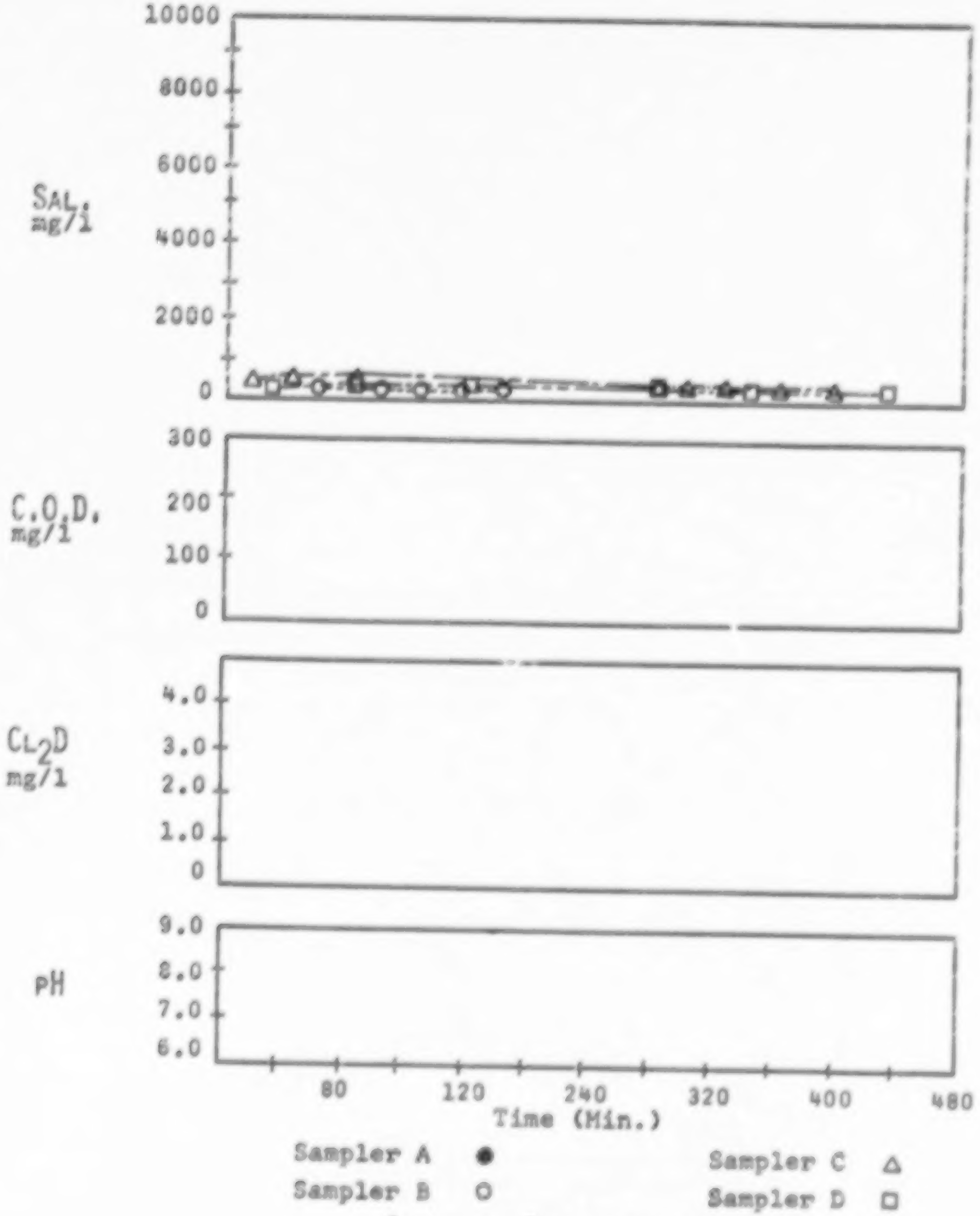
BACTERIAL RESULTS DPS #7
STORM PROFILE 5-11-72

Appendix 6-3 Storm Profile Results, DPS #7, May 11, 1972



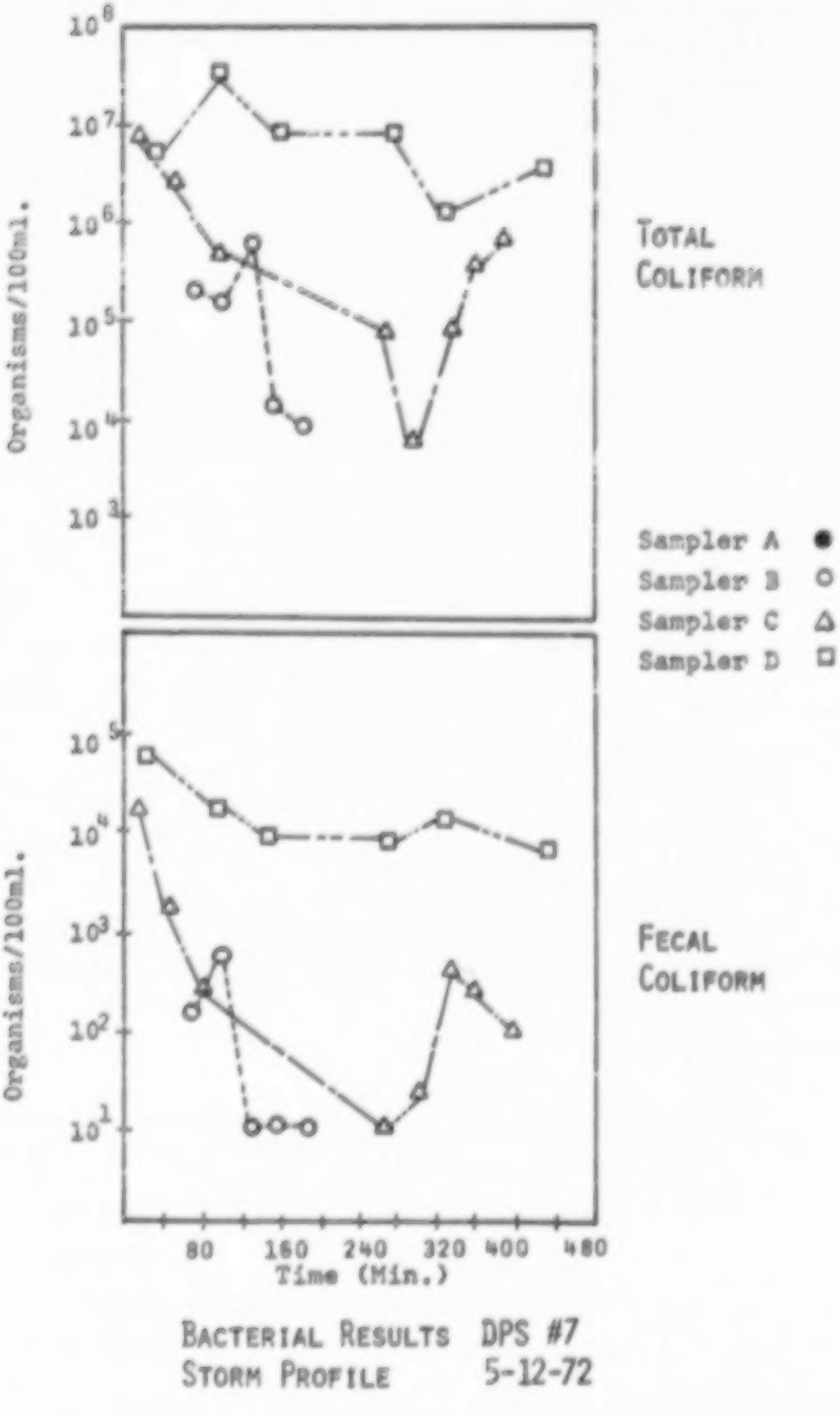
PHYSICAL PARAMETERS DPS #7
STORM PROFILE 5-12-72

Appendix 7-1 Storm Profile, DPS #7, May 12, 1972

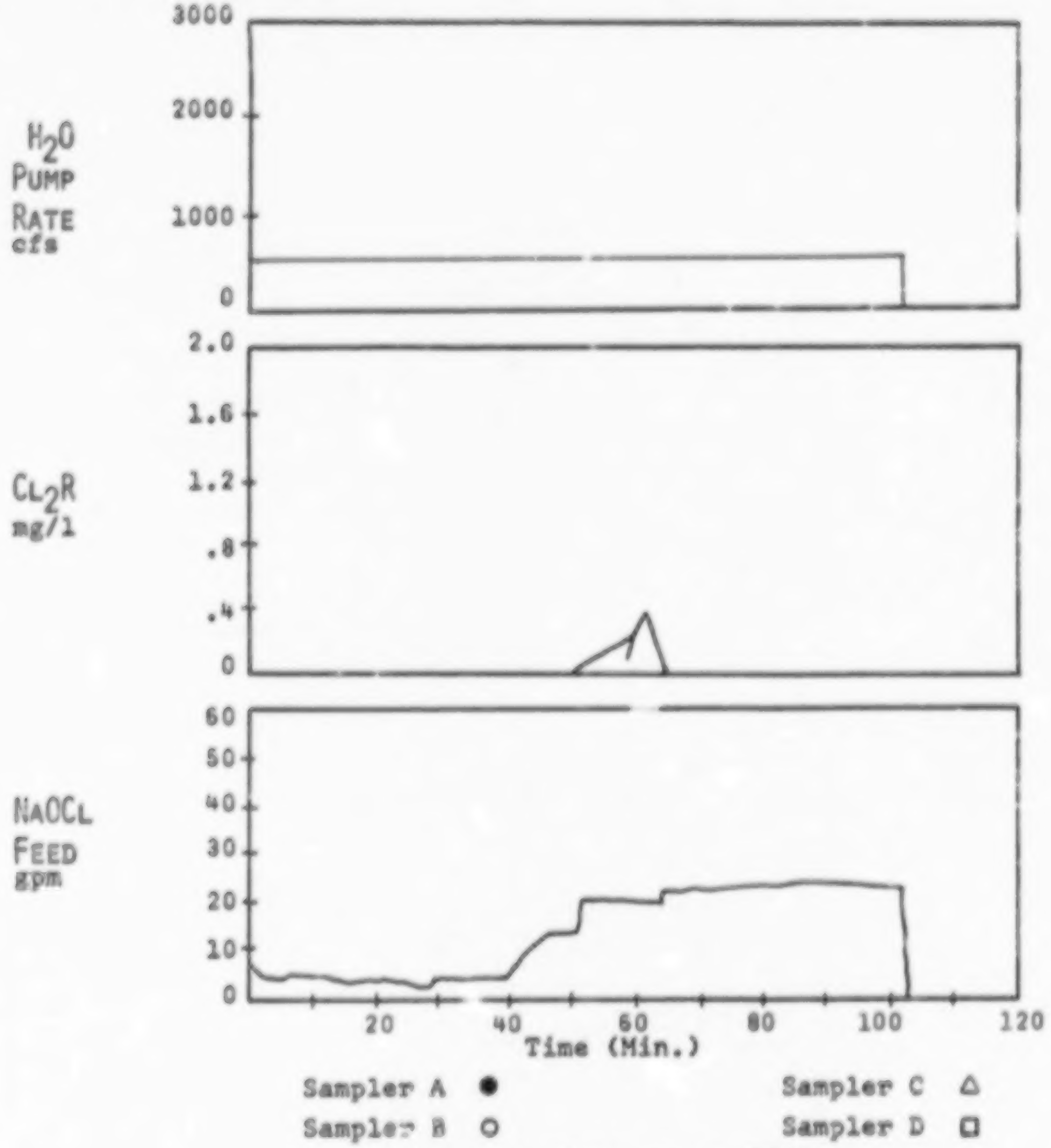


CHEMICAL PARAMETERS DPS #7
STORM PROFILE 5-12-72

Appendix 7-2 Storm Profile, DPS #7, May 12, 1972

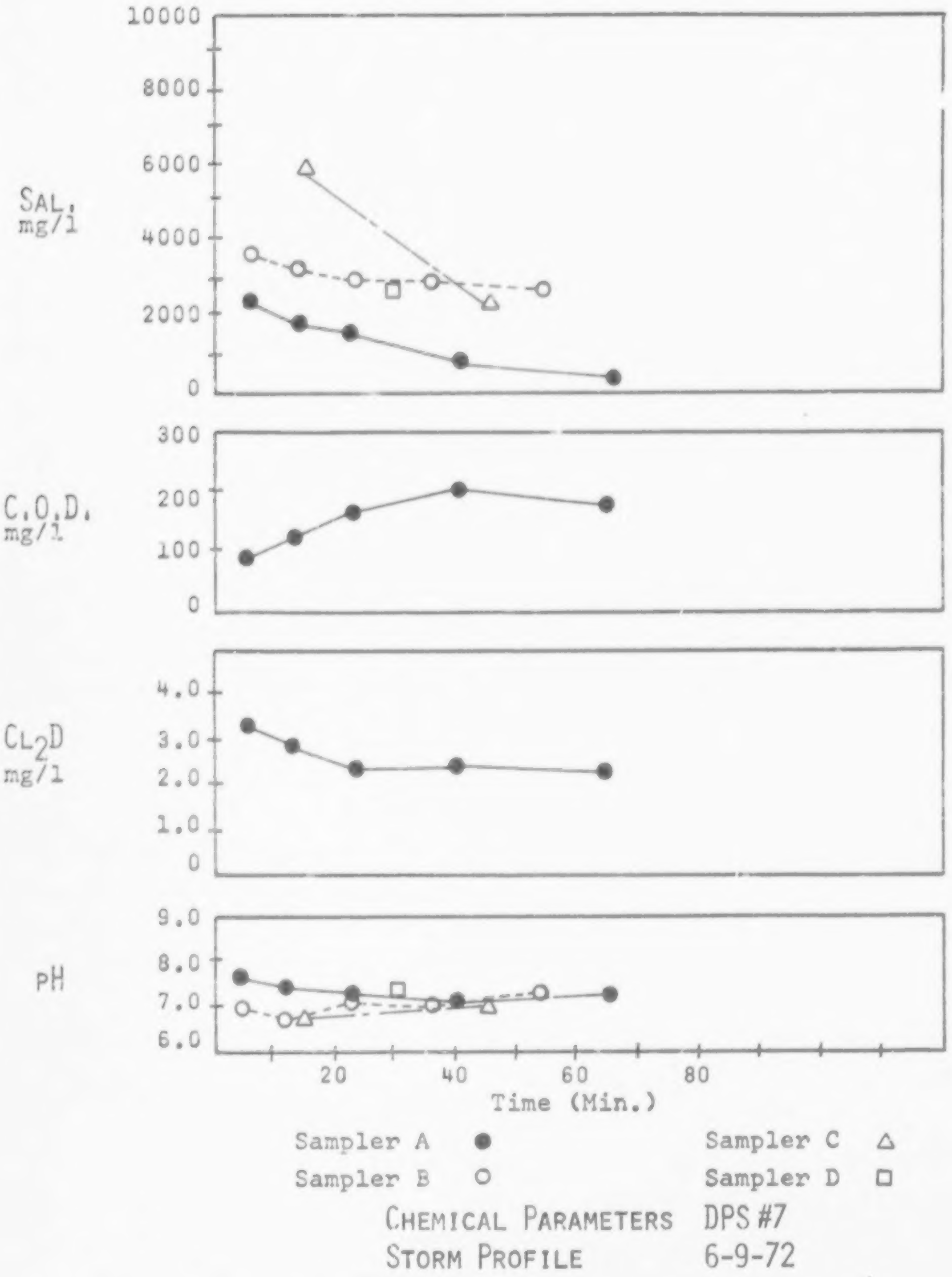


Appendix 7-3 Storm Profile Results, DPS #7, May 12, 1972

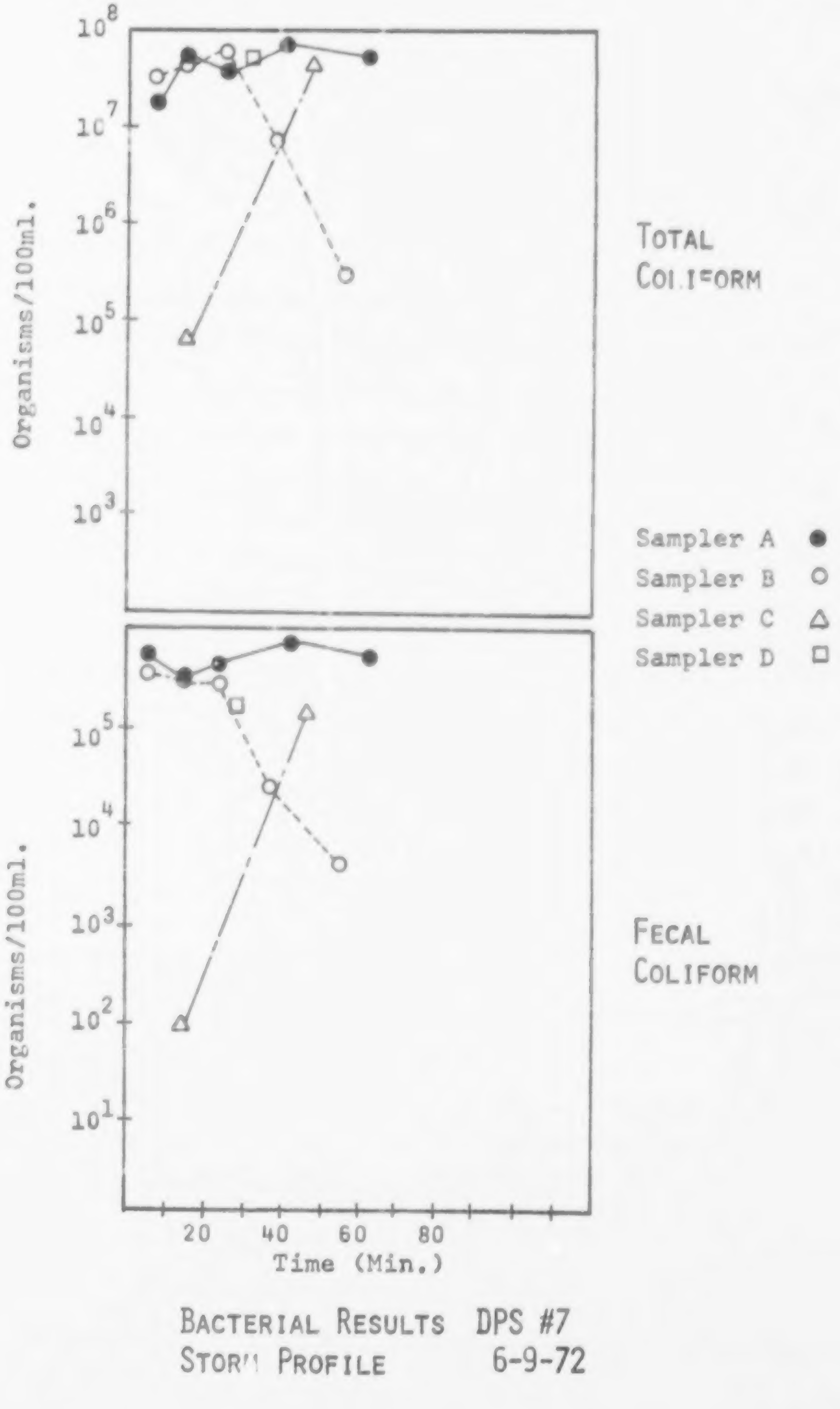


PHYSICAL PARAMETERS DPS #7
STORM PROFILE 6-9-72

Appendix 8-1 Storm Profile, DPS #7, June 9, 1972

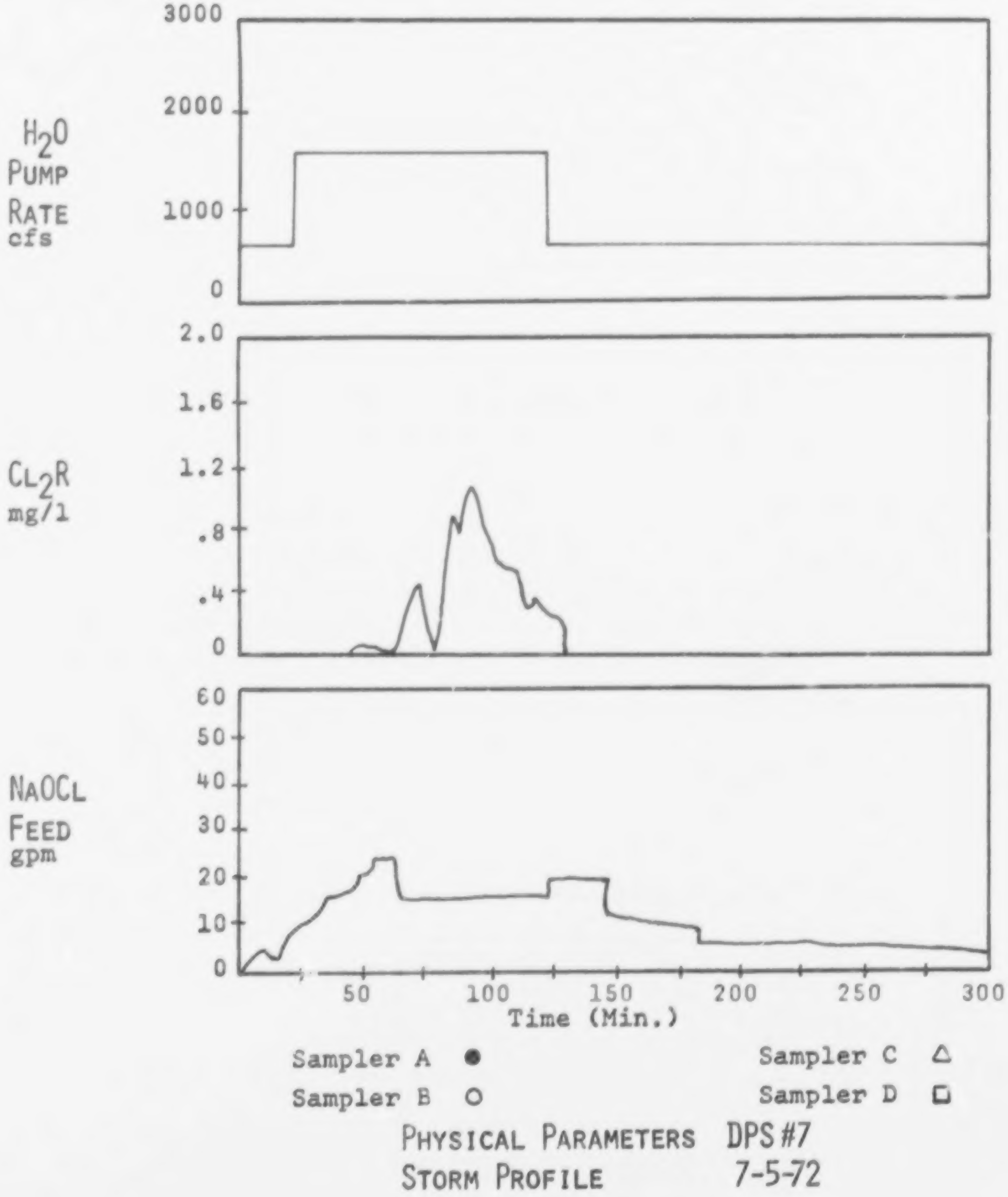


Appendix 8-2 Storm Profile, DPS #7, June 9, 1972

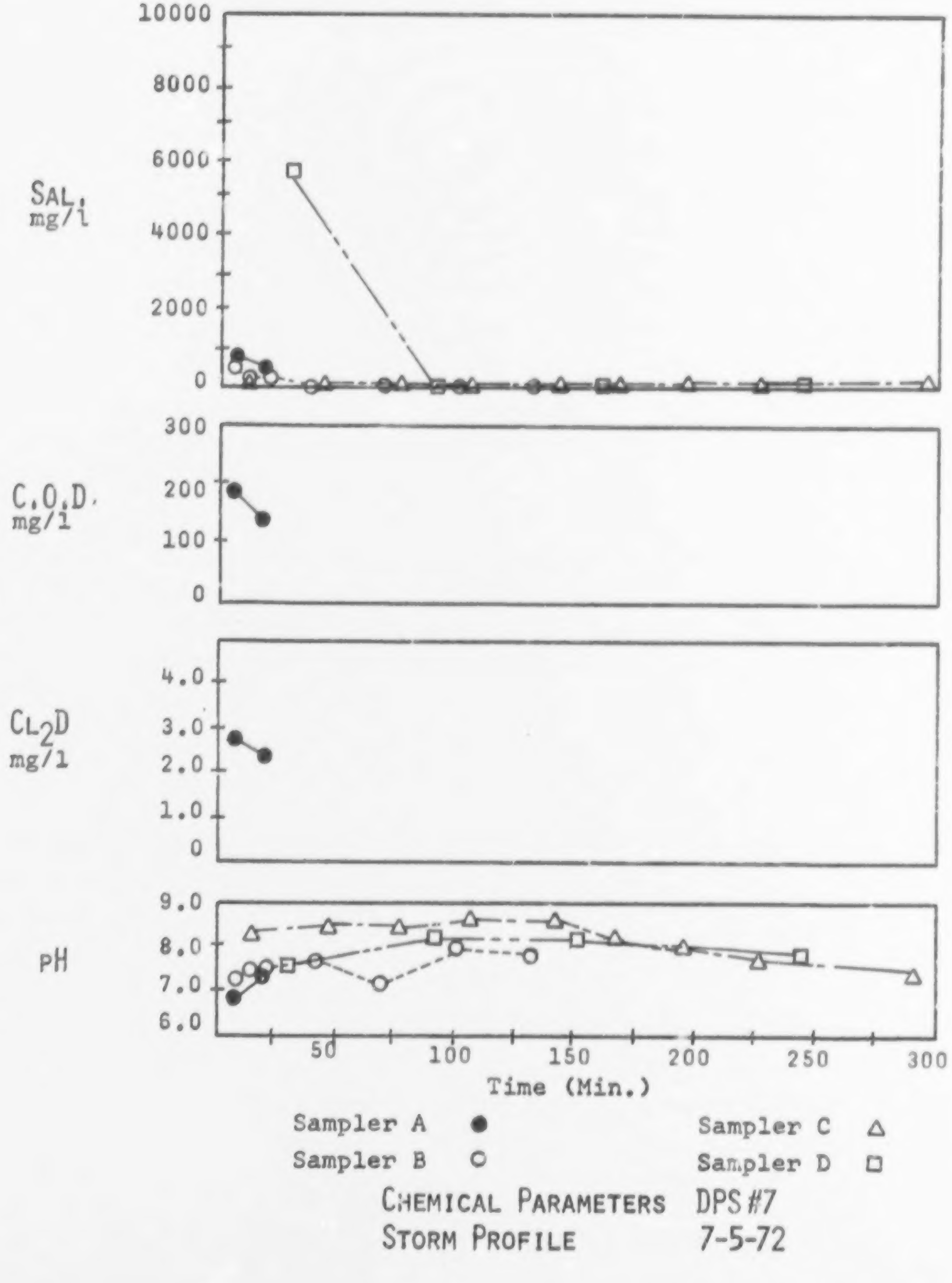


BACTERIAL RESULTS DPS #7
STORM PROFILE 6-9-72

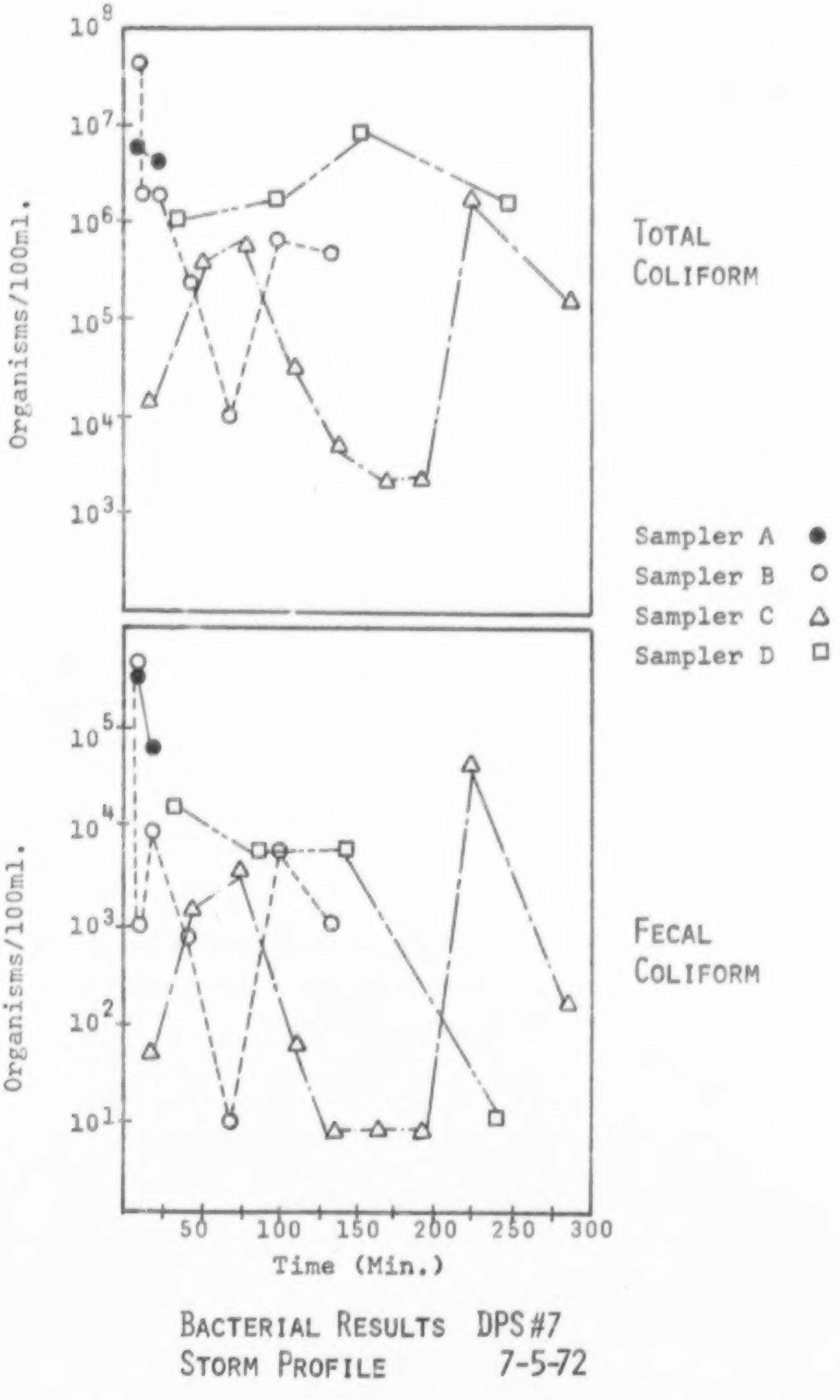
Appendix 8-3 Storm Profile Results, DPS #7, June 9, 1972



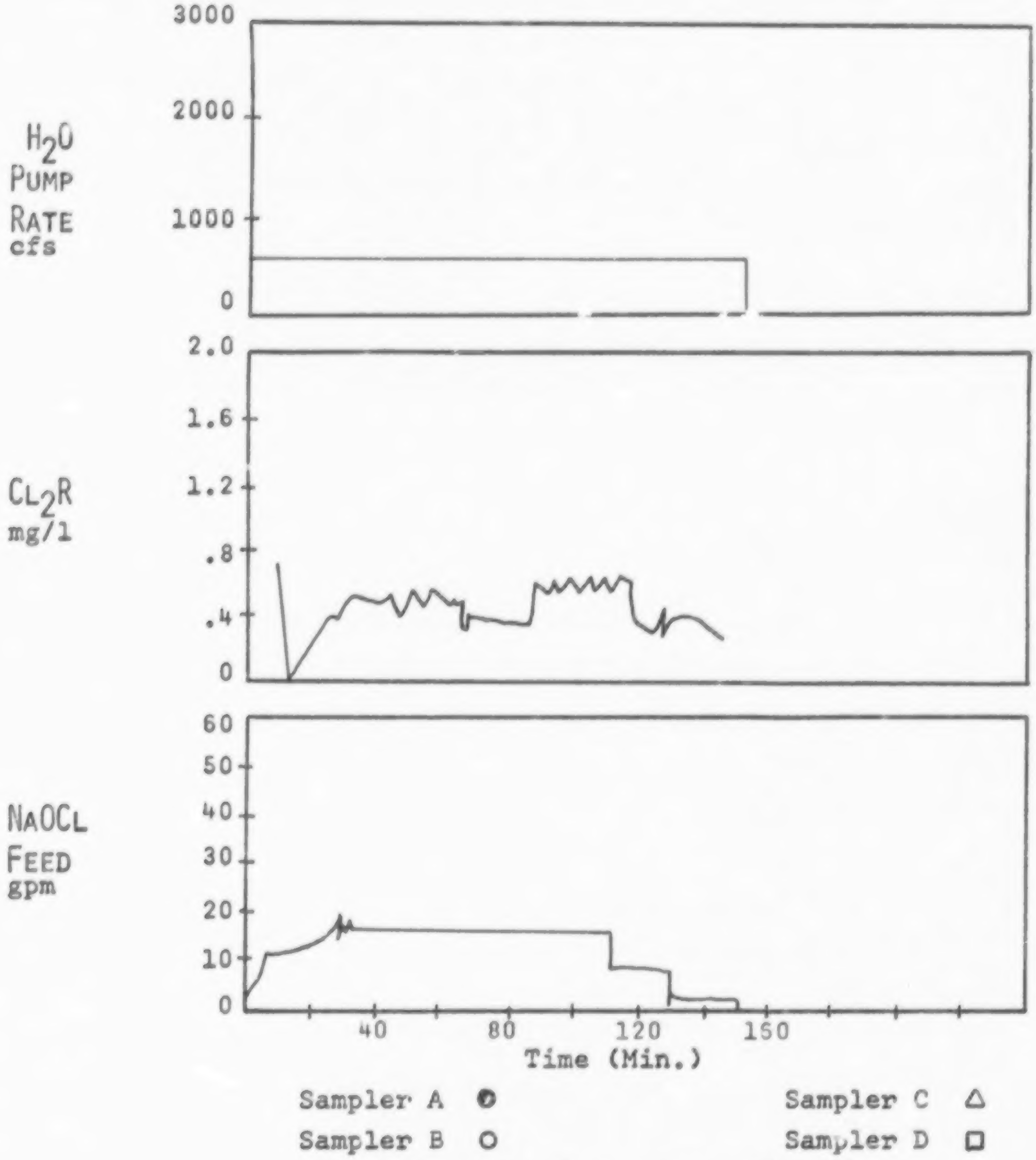
Appendix 9-1 Storm Profile, DPS #7, July 5, 1972



Appendix 9-2 Storm Profile, DPS #7, July 5, 1972

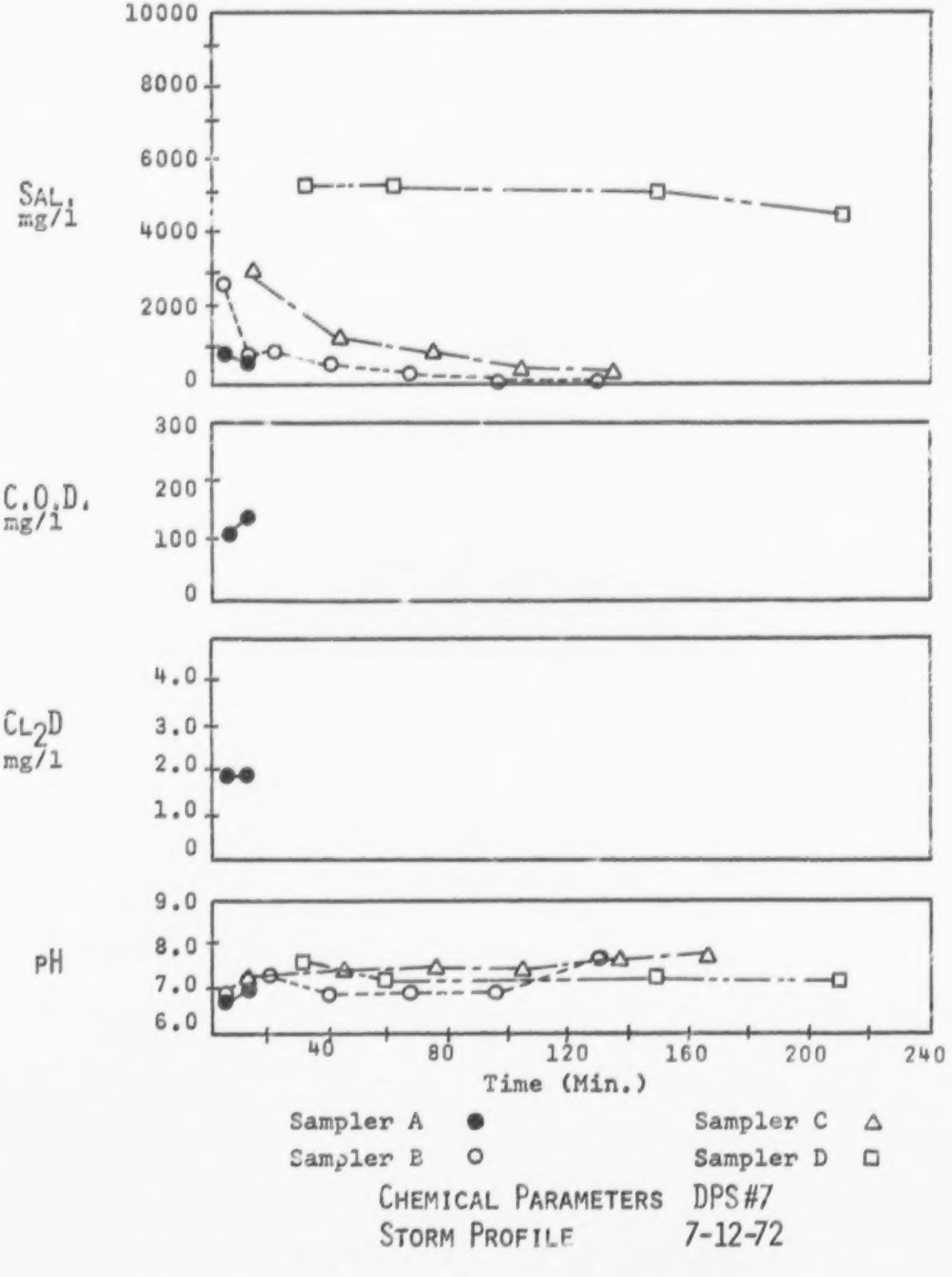


Appendix 9-3 Storm Profile Results, DPS #7, July 5, 1972

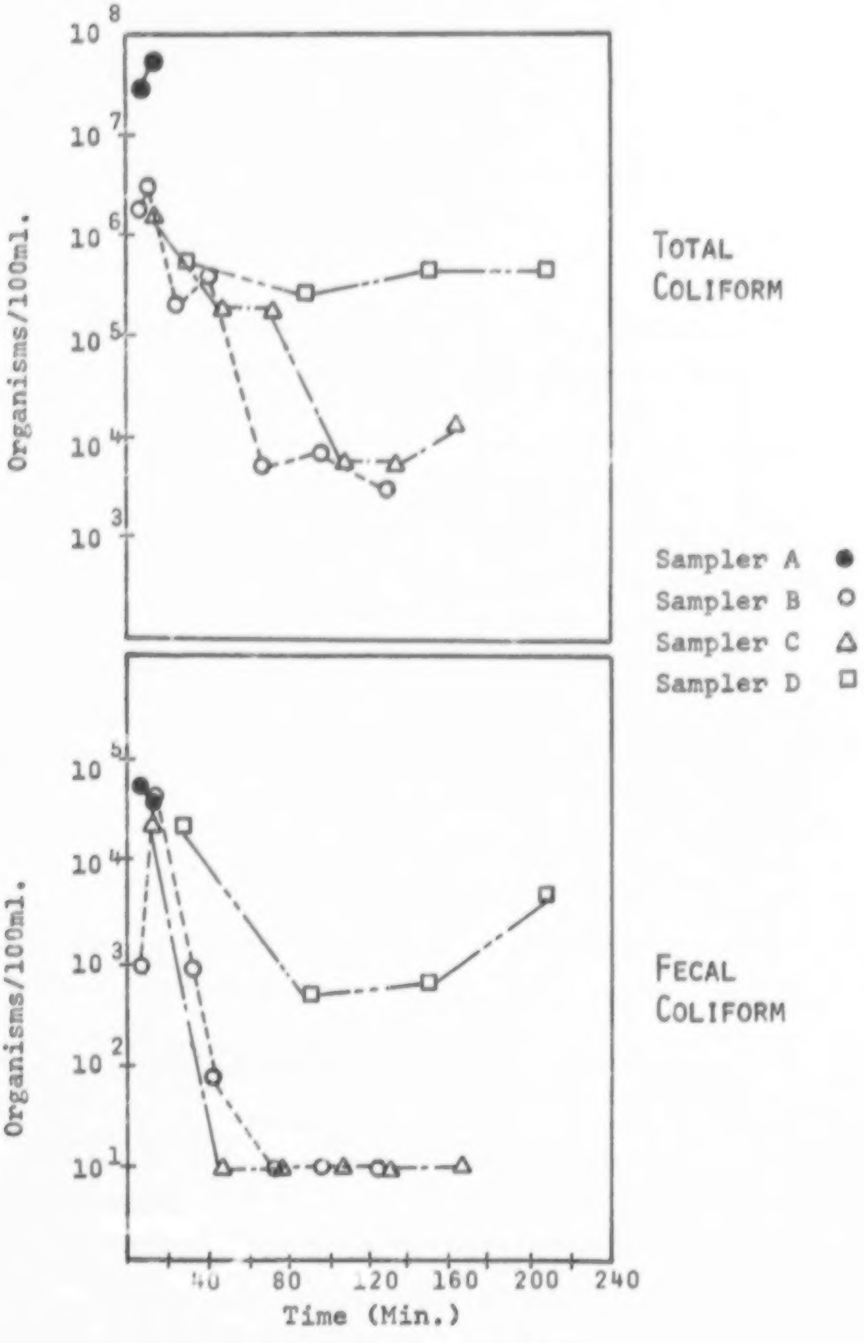


PHYSICAL PARAMETERS DPS #7
STORM PROFILE 7-12-72

Appendix 10-1 Storm Profile, DPS #7, July 12, 1972

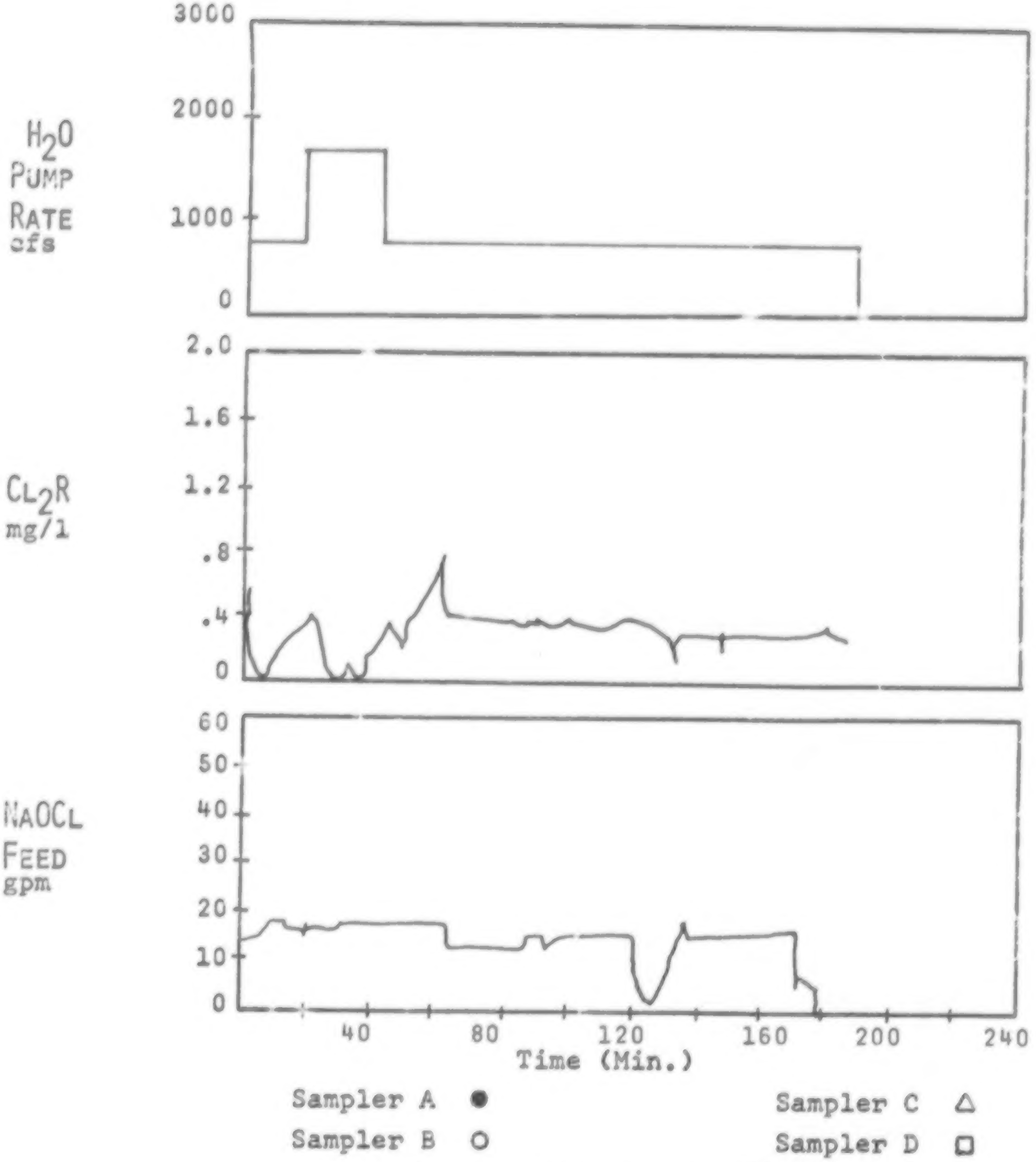


Appendix 10-2 Storm Profile, DPS #7, July 12, 1972



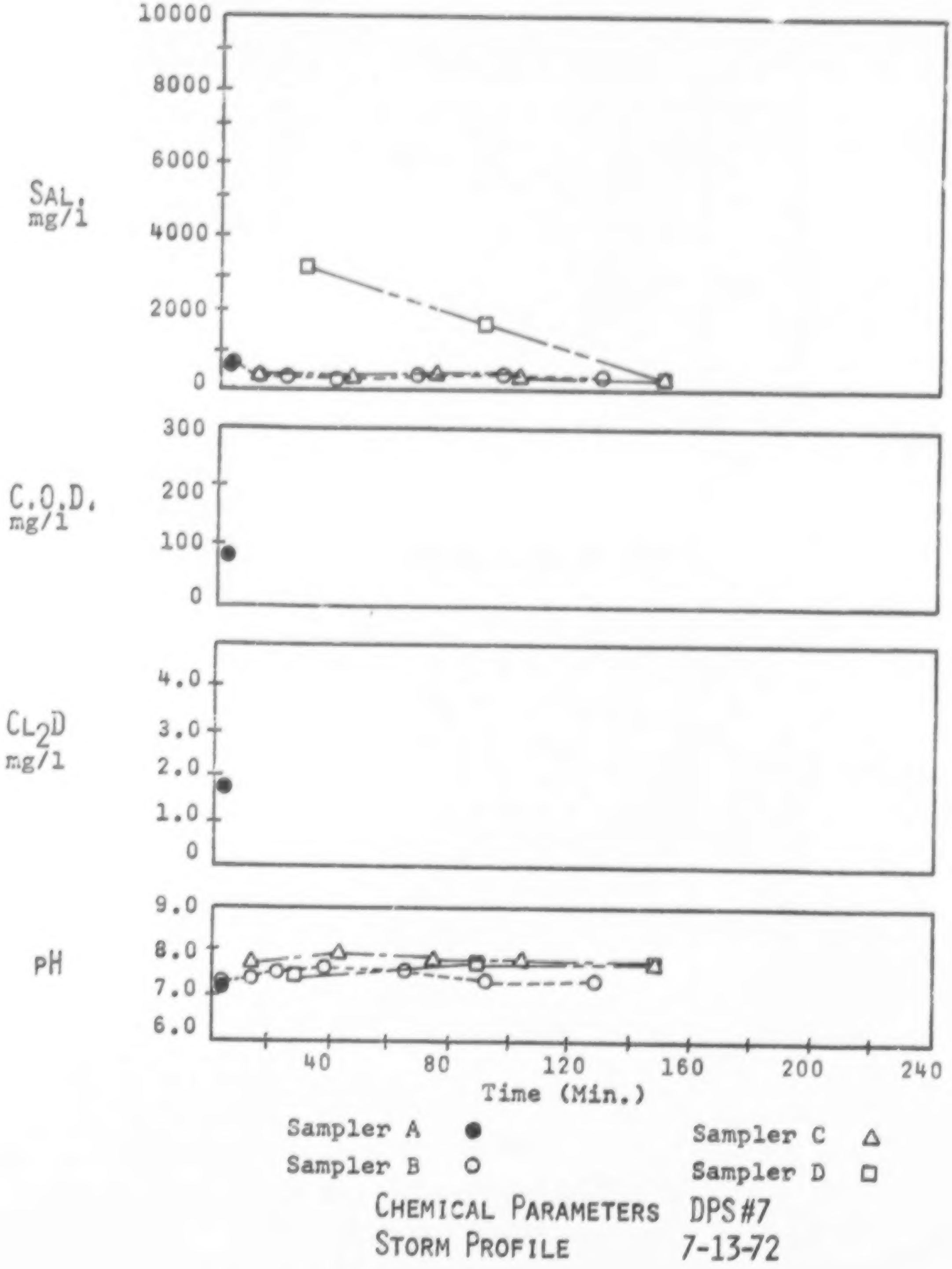
BACTERIAL RESULTS DPS #7
STORM PROFILE 7-12-72

Appendix 10-3 Storm Profile Results, DPS #7, July 12, 1972

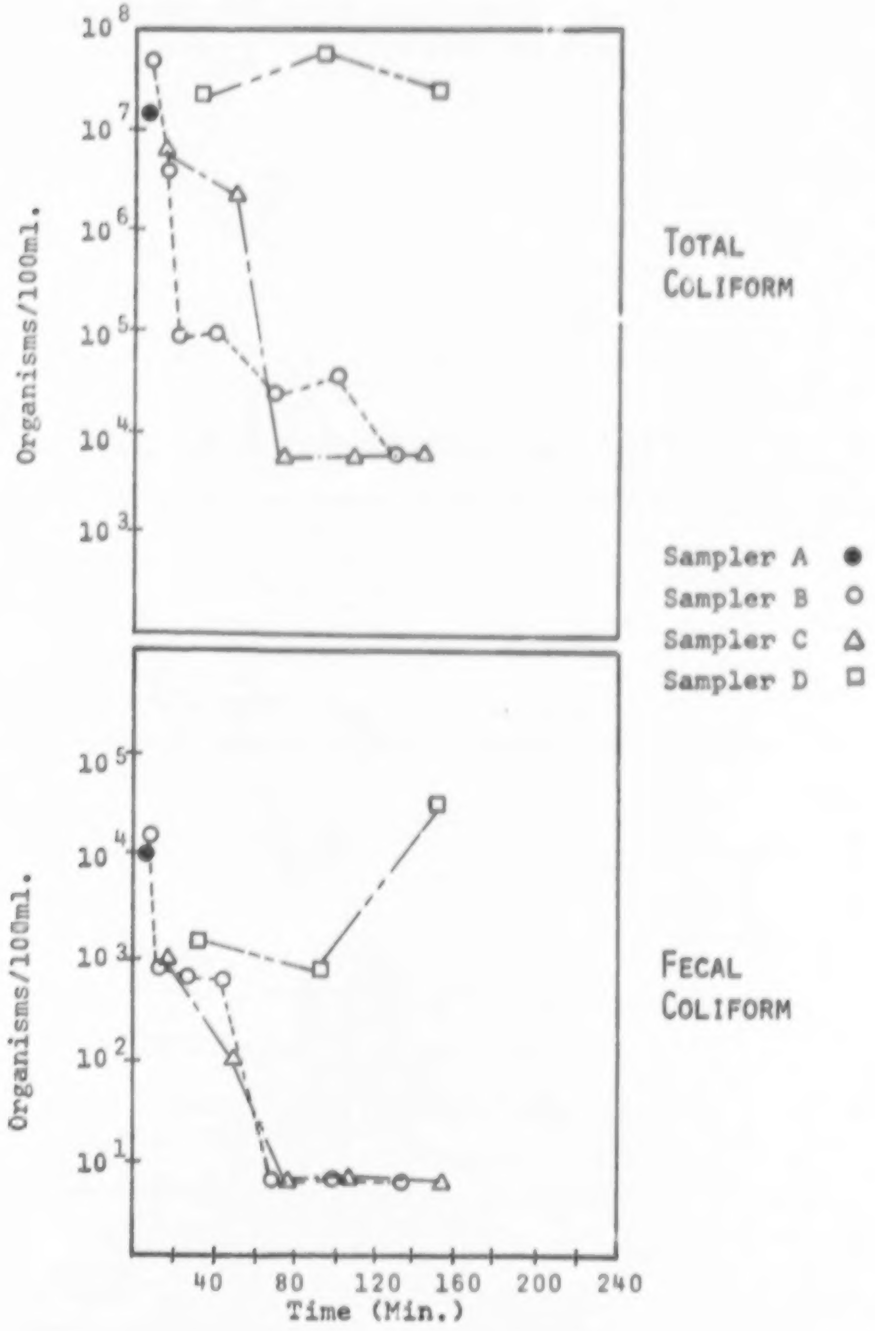


PHYSICAL PARAMETERS DPS #7
STORM PROFILE 7-13-72

Appendix 11-1 Storm Profile, DPS #7 July 13, 1972

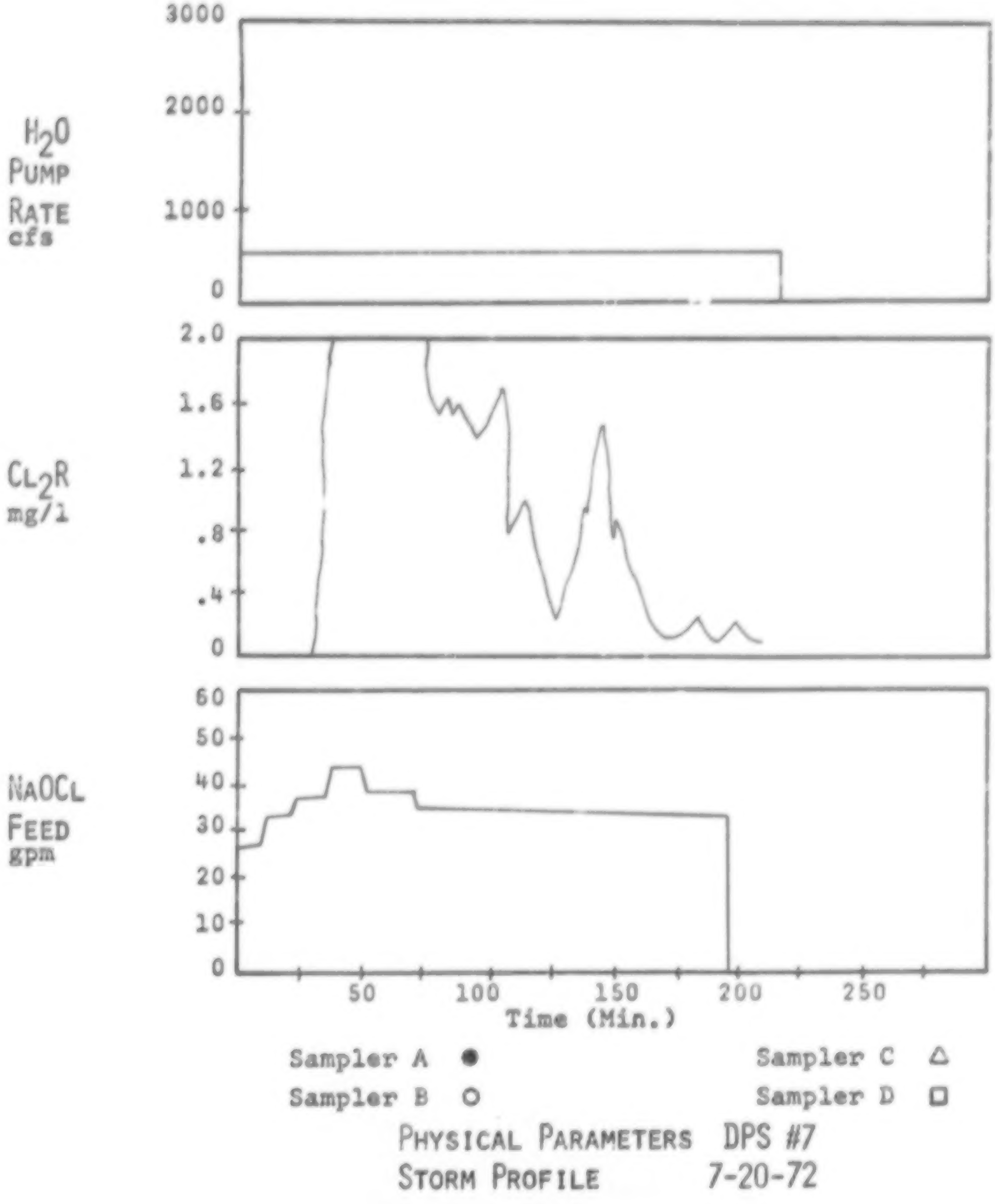


Appendix 11-2 Storm Profile, DPS #7, July 13, 1972

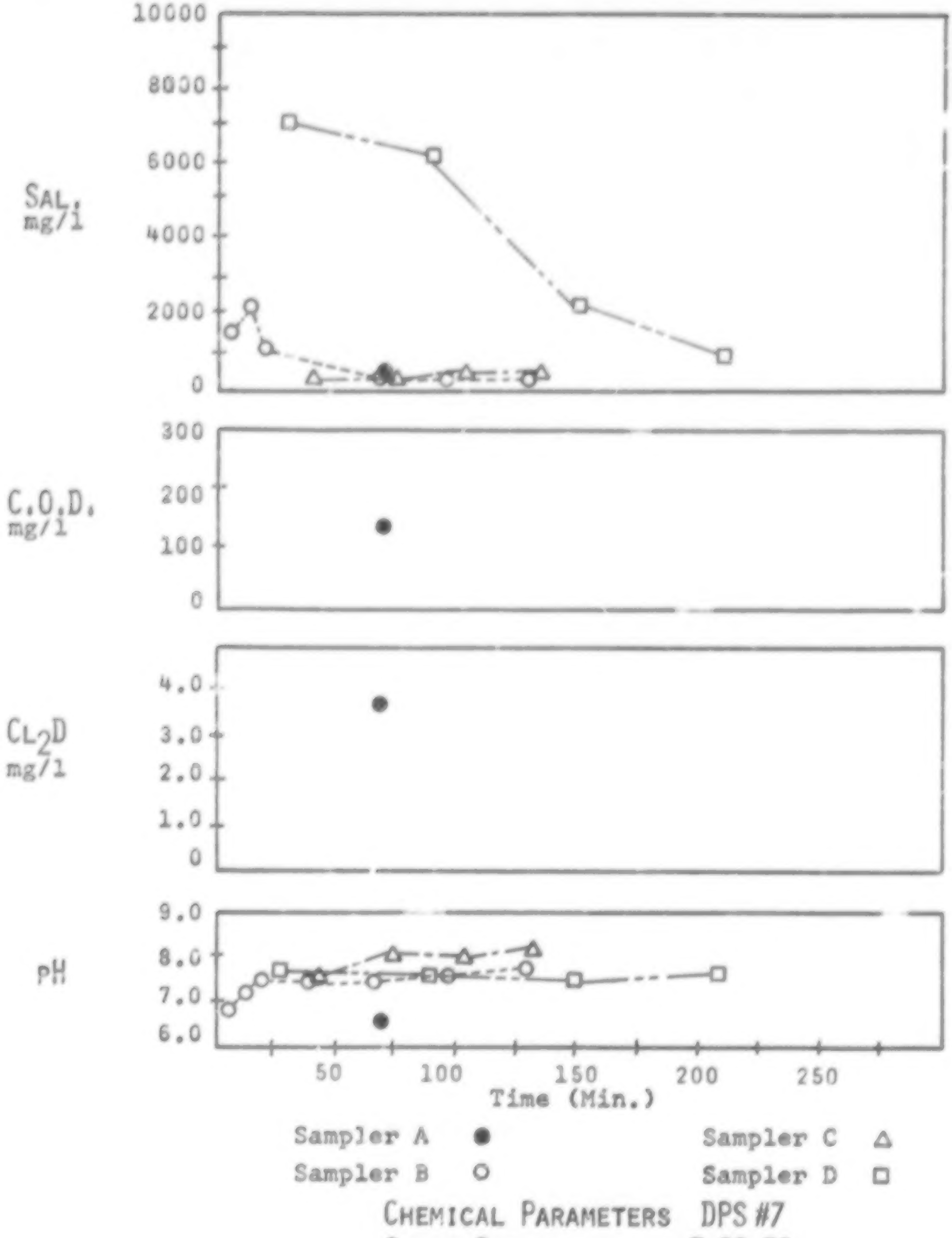


BACTERIAL RESULTS DPS #7
STORM PROFILE 7-13-72

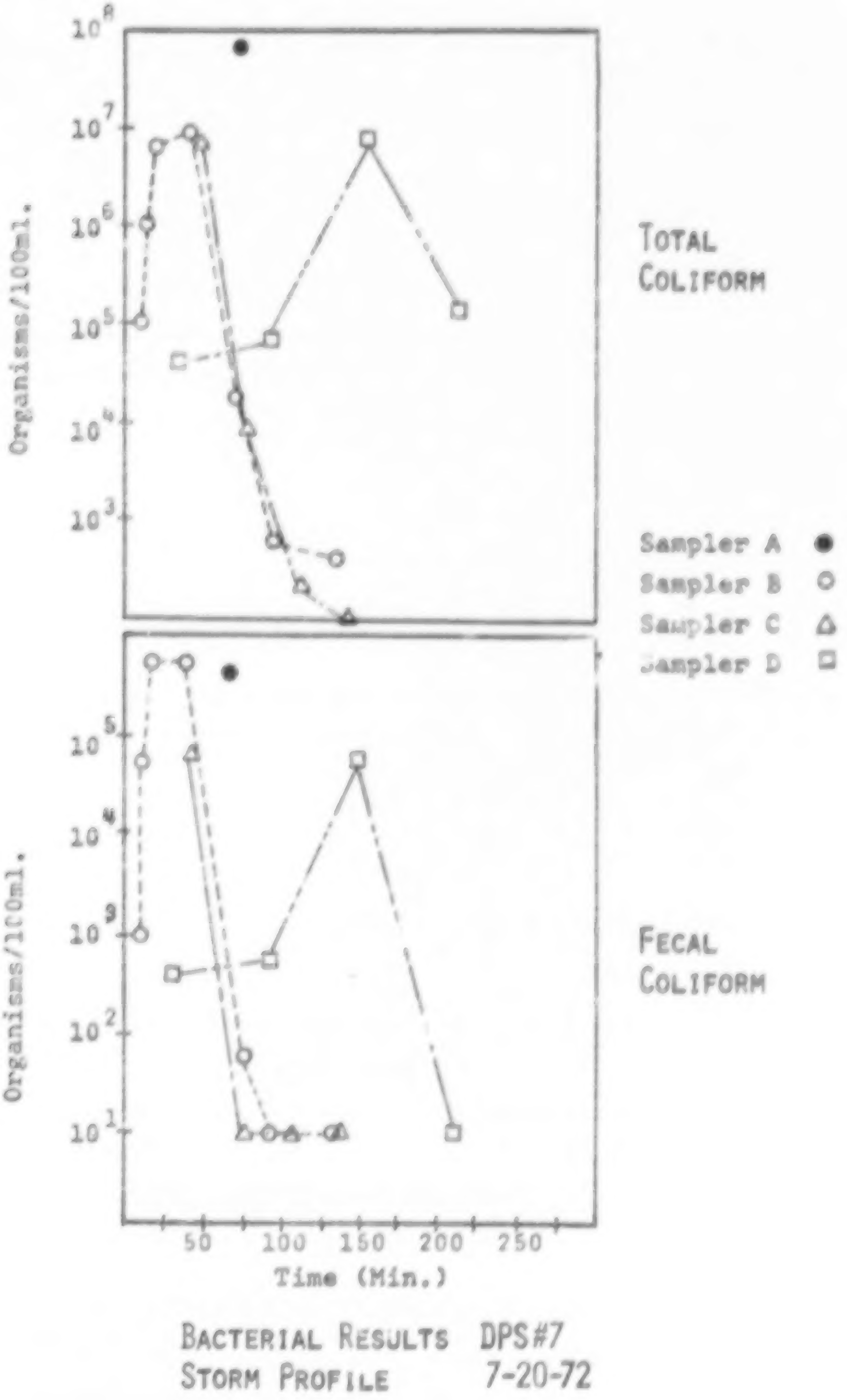
Appendix 11-3 Storm Profile Results, DPS #7, July 13, 1972



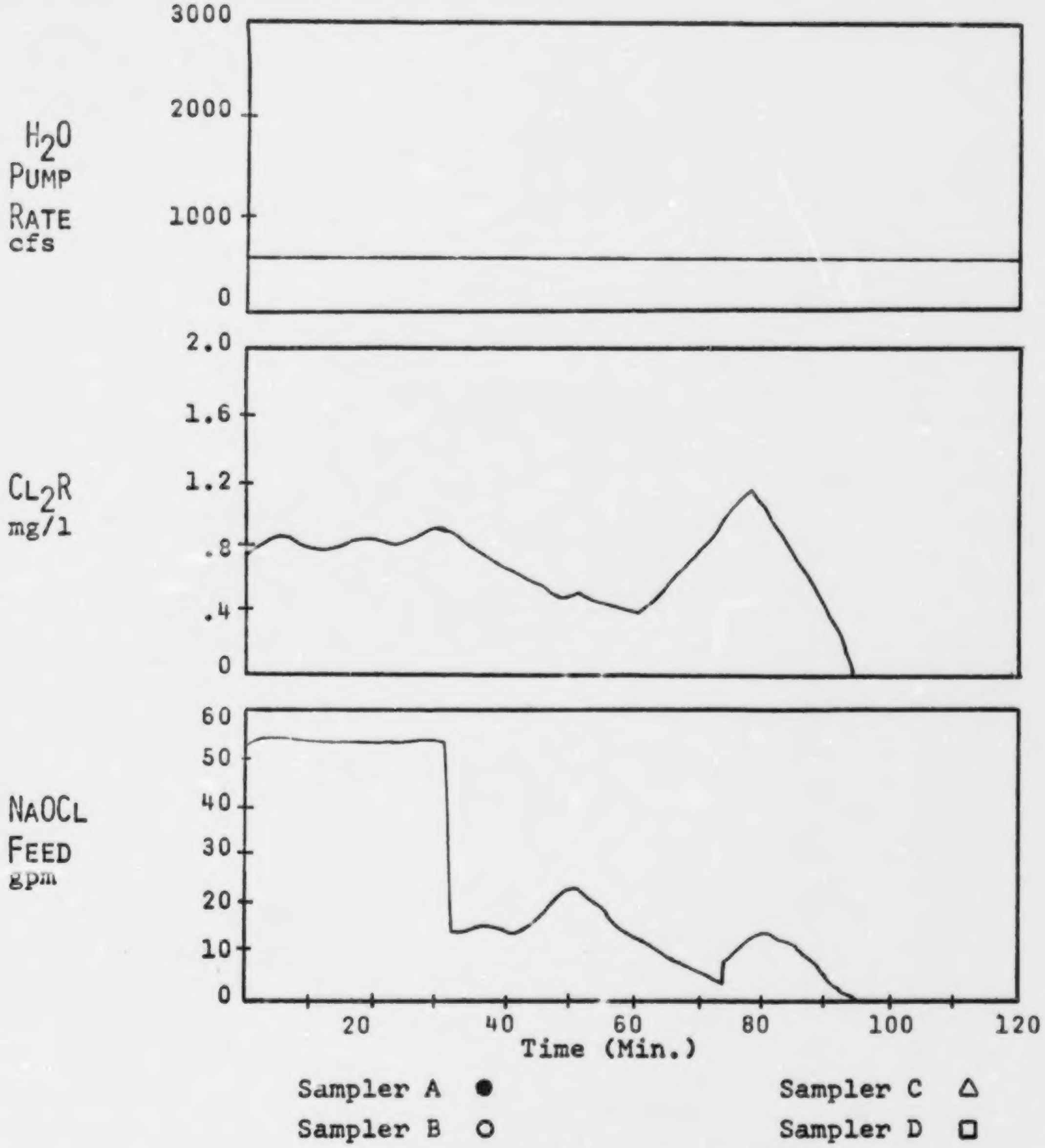
Appendix 12-1 Storm Profile, DPS #7, July 20, 1972



Appendix 12-2 Storm Profile, DPS #7, July 20, 1972

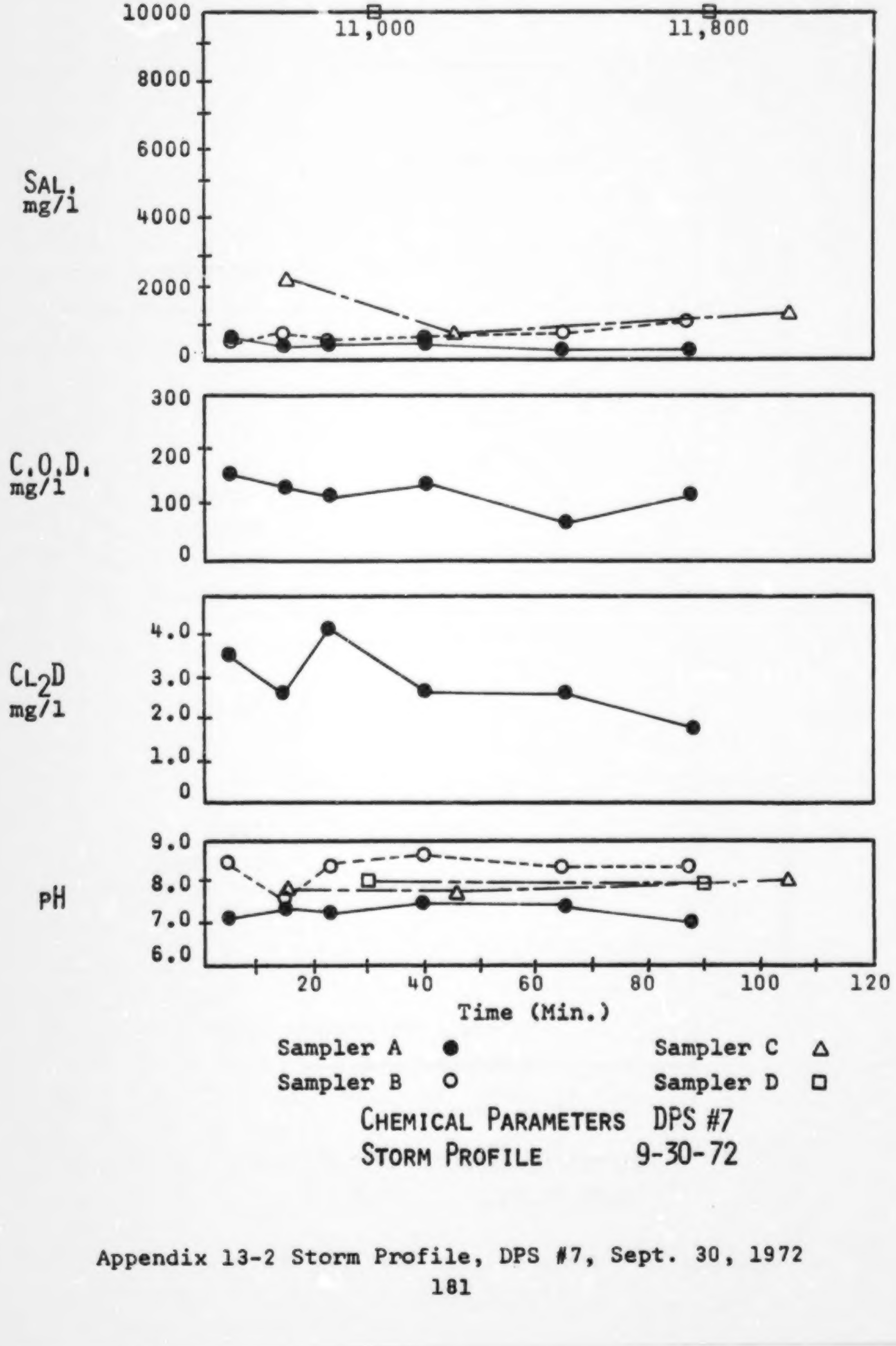


Appendix 12-3 Storm Profile Results, DPS #7, July 20, 1972

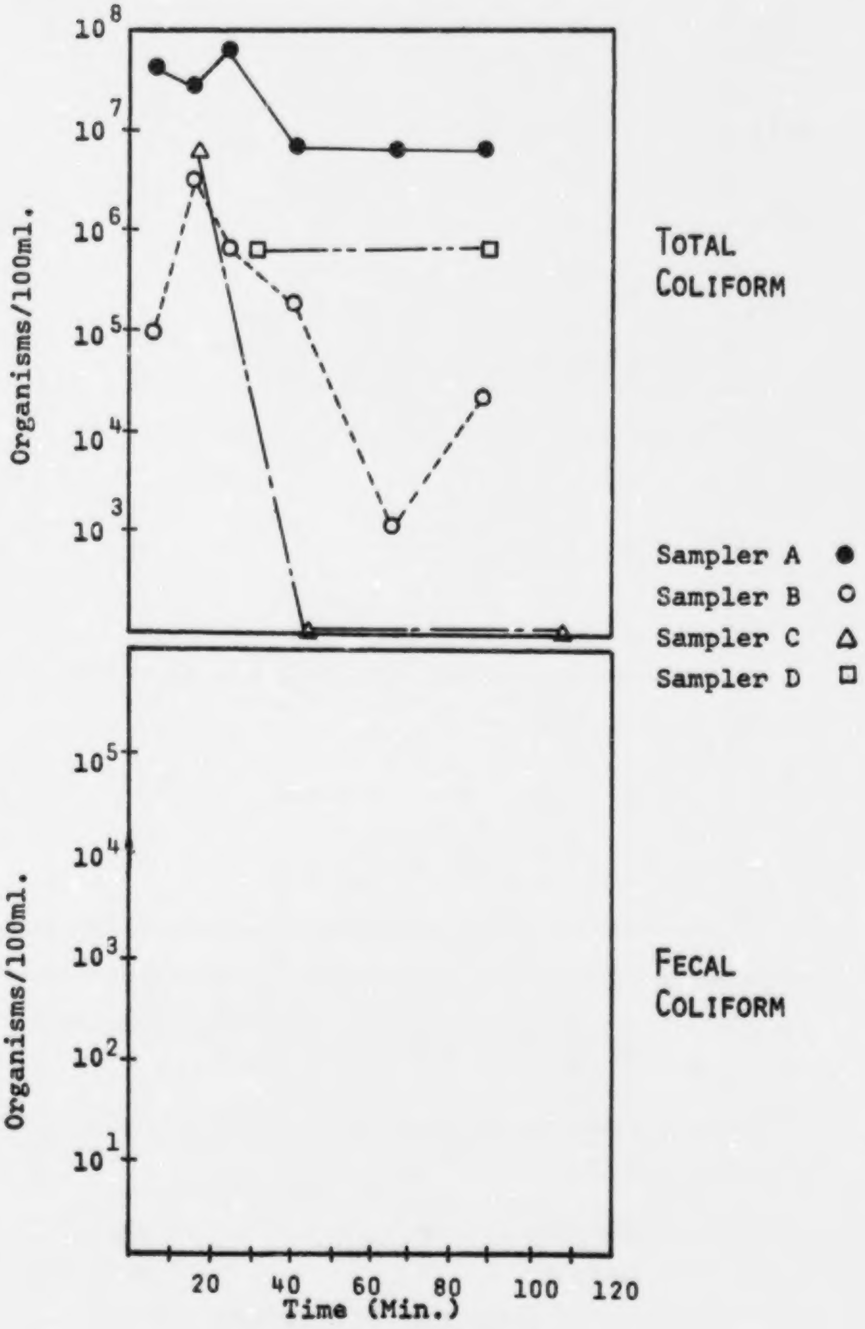


PHYSICAL PARAMETERS DPS#7
STORM PROFILE 9-30-72

Appendix 13-1 Storm Profile, DPS #7, Sept. 30, 1972

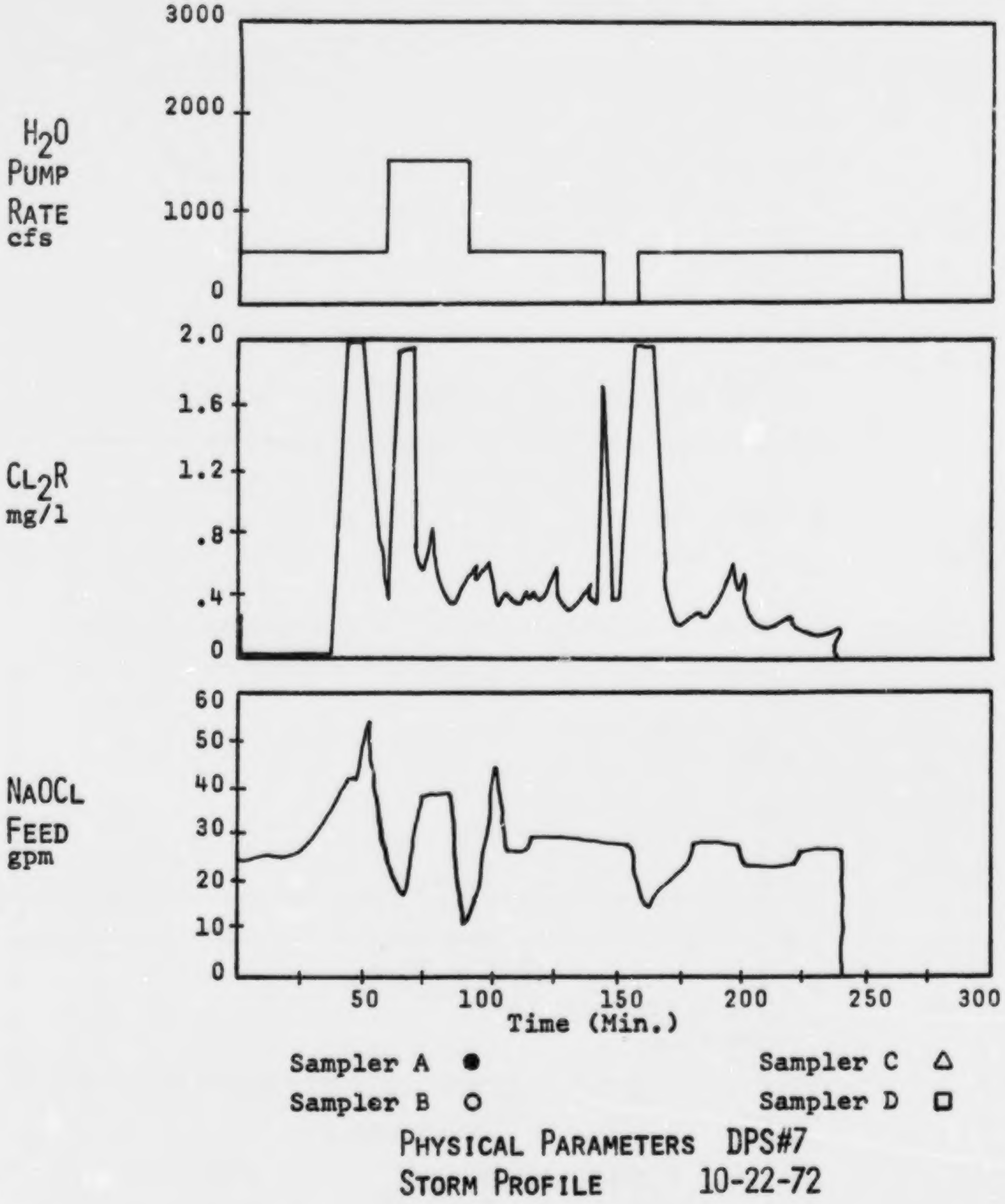


Appendix 13-2 Storm Profile, DPS #7, Sept. 30, 1972

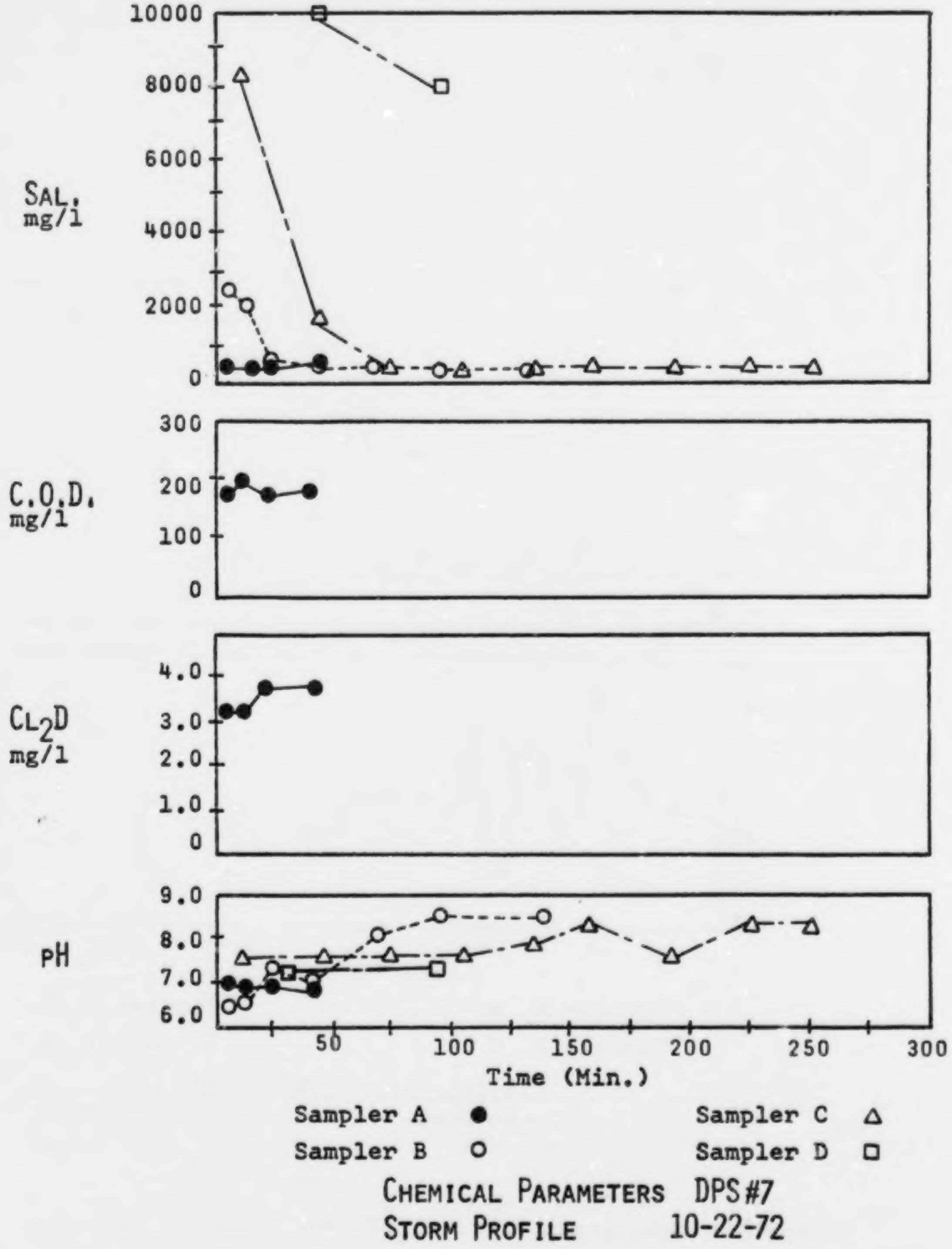


BACTERIAL RESULTS DPS #7
STORM PROFILE 9-30-72

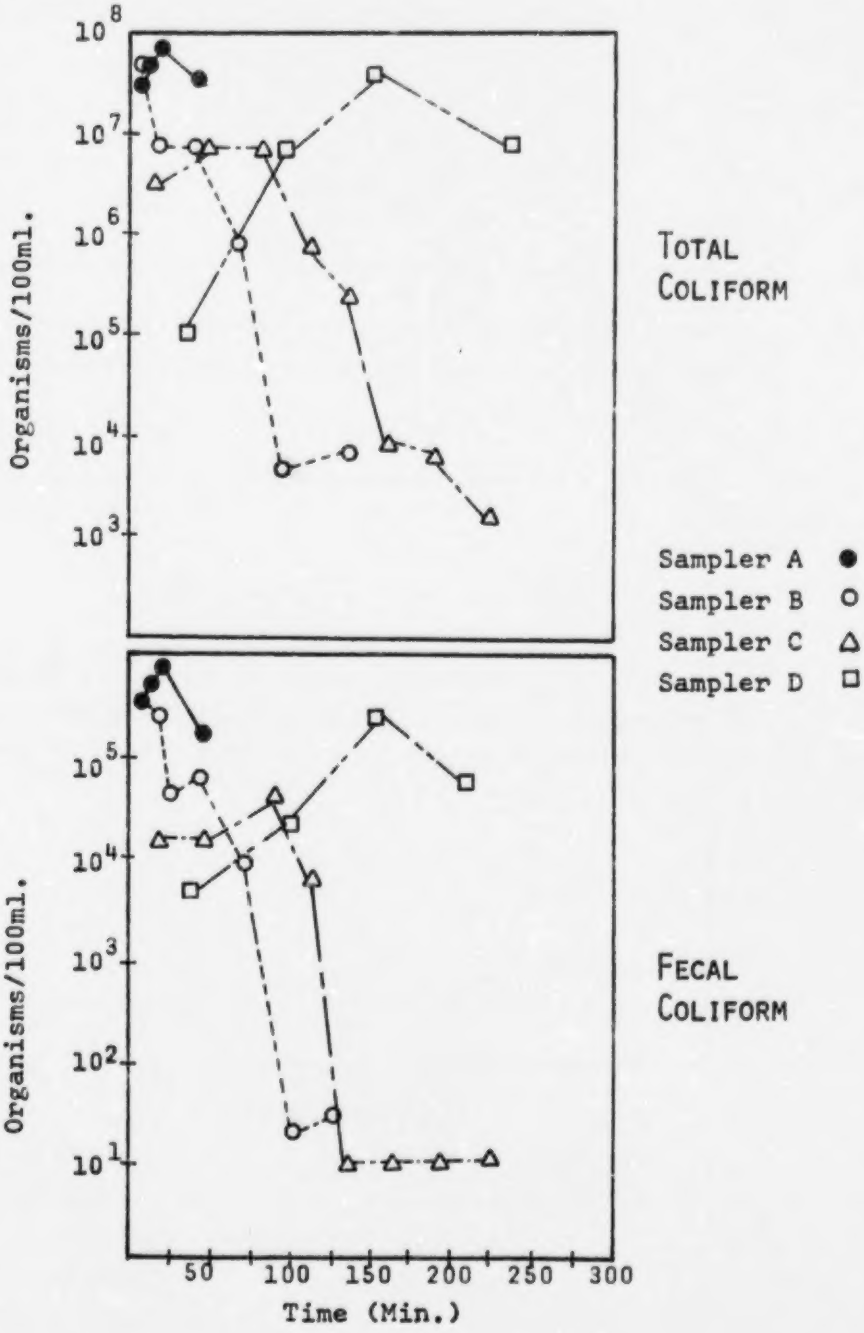
Appendix 13-3 Storm Profile Results, DPS #7, Sept. 30, 1972



Appendix 14-1 Storm Profile, DPS #7, Oct. 22, 1972

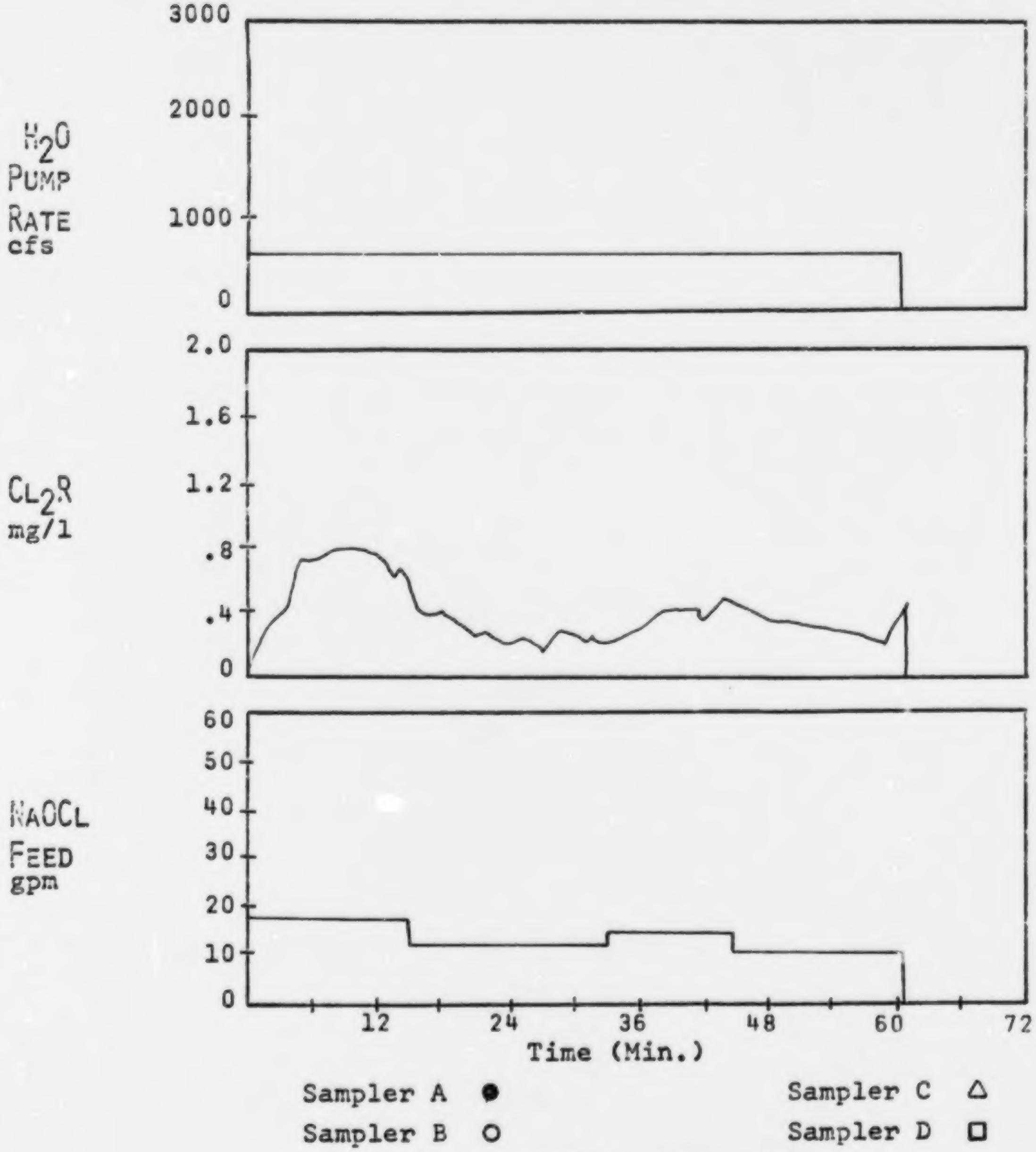


Appendix 14-2 Storm Profile, DPS #7, Oct. 22, 1972



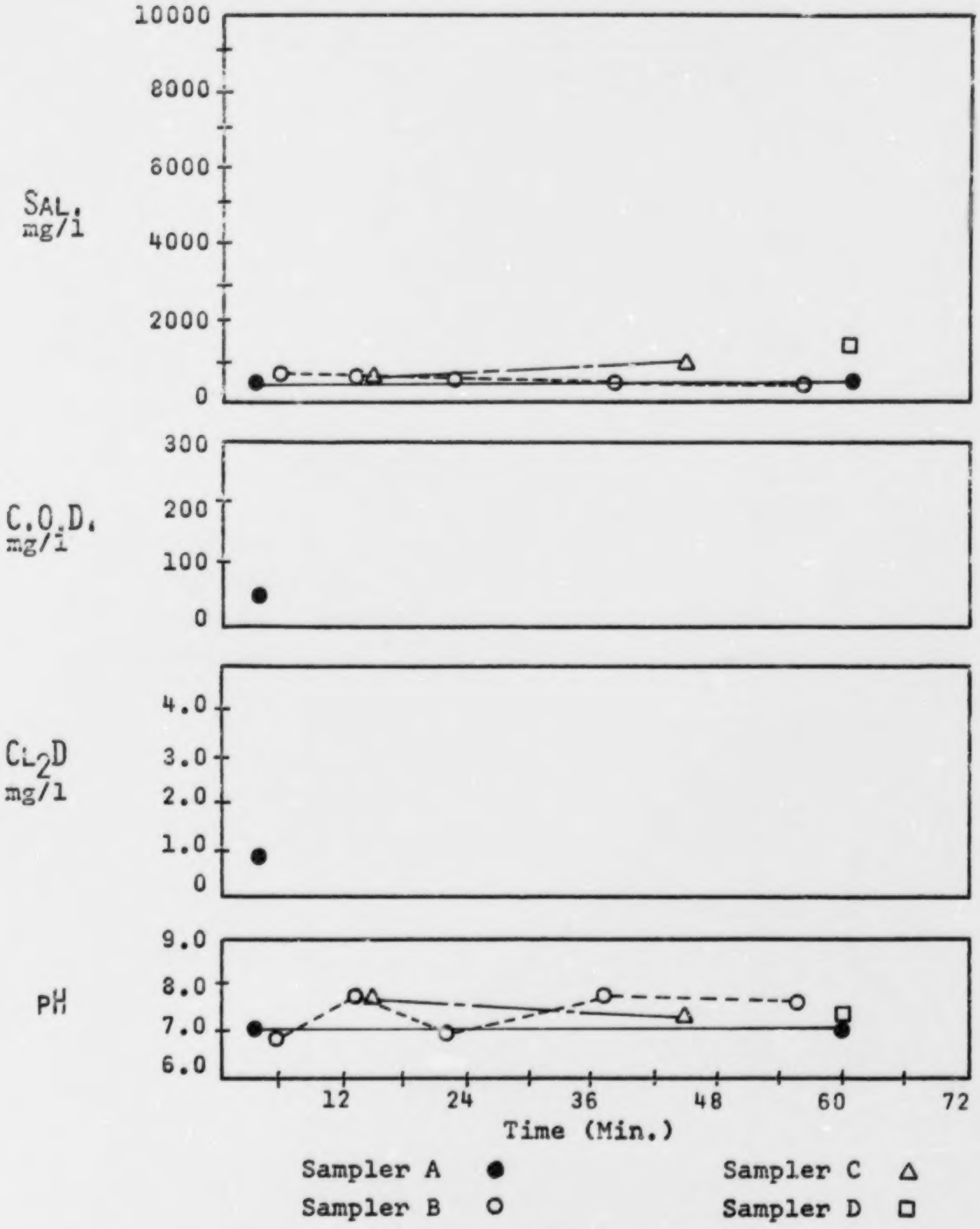
BACTERIAL RESULTS DPS#7
STORM PROFILE 10-22-72

Appendix 14-3 Storm Profile Results, DPS #7, Oct. 22, 1972



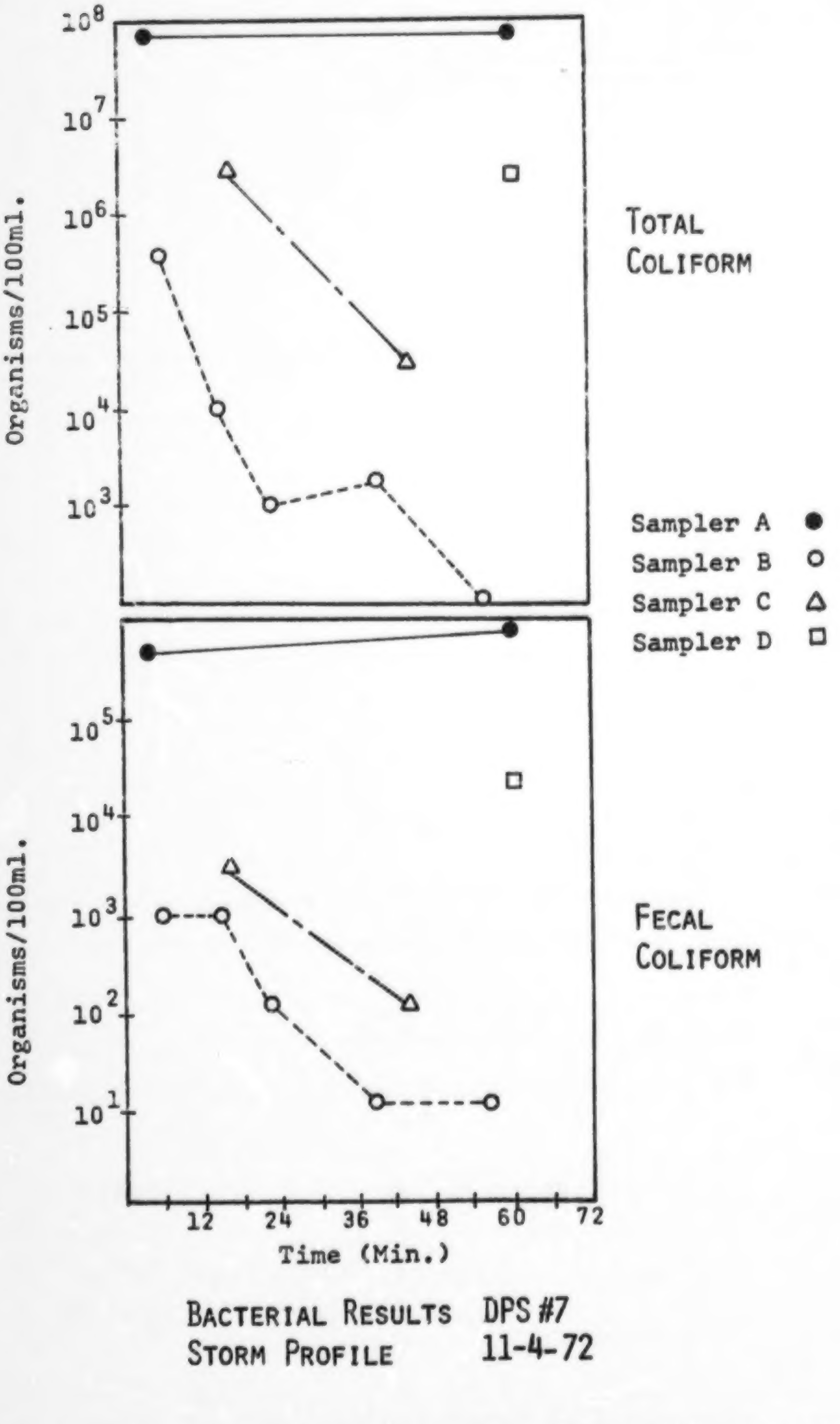
PHYSICAL PARAMETERS DPS #7
STORM PROFILE 11-4-72

Appendix 15-1 Storm Profile, DPS #7, Nov. 4, 1972



CHEMICAL PARAMETERS DPS #7
STORM PROFILE 11-4-72

Appendix 15-2 Storm Profile, DPS #7, Nov. 4, 1972



Appendix 15-3 Storm Profile Results, DPS #7, Nov. 4, 1972

*U.S. GOVERNMENT PRINTING OFFICE:1973 546-312/158 1-3